

BBC

Sky at Night
MAGAZINE

DISCOVER SPACE
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The Complete Guide to **ASTRO PHOTOGRAPHY**



**Photograph the Moon,
meteors and Milky Way**

Expert processing tips
to enhance your photos

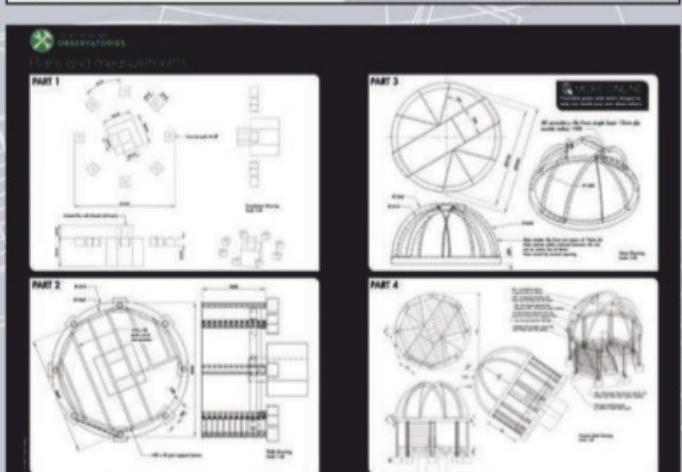
**Create short films
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Night sky targets for
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The right kit for imaging
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SPECIAL EDITION



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MAKERS OF **Sky at Night**
MAGAZINE

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Welcome



My first astrophoto was a shot of the constellation of Orion with a DSLR camera on a tripod. It was a little out of focus but still gives me a great sense of pride. The thrill of capturing that shot is something I'll never forget. But as proud as I was of my first astro image, I soon began to wonder how it could be improved. What could I do to increase the sharpness of the stars, how could I get my photos to show the orange-red colour of Betelgeuse and capture

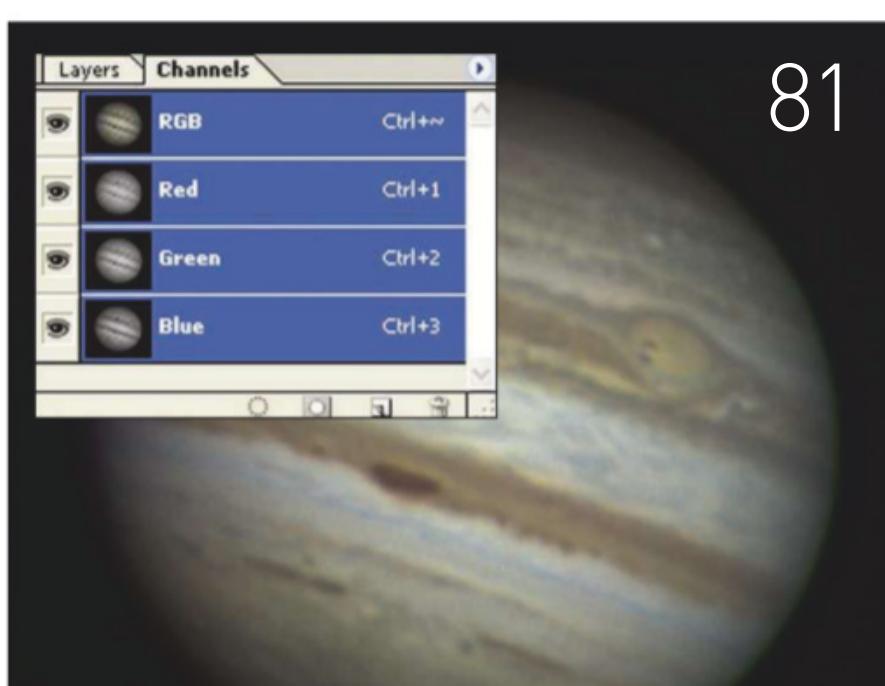
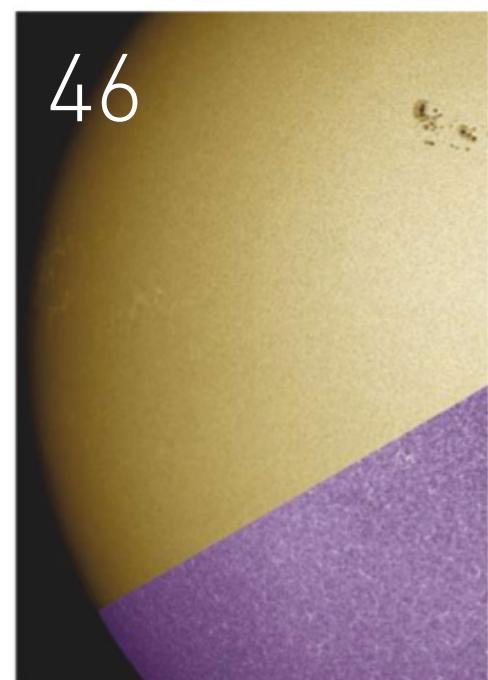
more detail in Orion's Sword?

Trying to answer those questions led to a long period of pestering fellow astrophotographers for advice, reading up on the subject in books and magazines, and poring over catalogues to find more capable equipment. Needless to say, there was also a lot of trial and error with my camera, and more than a few wasted nights under the stars.

Gradually, though, the images I was able to capture improved. And while there's still a lot of tricks left for me to learn and techniques I need to master, the challenge remains as inspiring as ever. I may not be able to repeat the thrill of capturing my first astro image but seeing the improvement in the results of my efforts since then is exhilarating in a whole other way.

We want you to experience that same exhilaration, which is where *The Complete Guide to Astrophotography* comes in. It will help you go from thrilled beginner to experienced astro imager with an ever-widening spectrum of skills. On the pages that follow you'll find essential tips on the best ways to start imaging the night sky, the best equipment to do it with and the best software for making the most of your images after you've taken them. So let's get started...

Chris Bramley, Editor





CONTENTS

7 Astrophotography

08 Nightscapes

Capture striking images of the night sky without any expensive equipment or even a telescope – and learn how to compose your shots for the most eye-catching results.

20 The Moon

All the ways you can exploit the incredible imaging potential of our closest companion, from simple smartphone snaps to highly detailed mosaics.

32 The planets

Discover how to record Earth's neighbours in the Solar System through your telescope, from tiny Mercury to the mighty gas giant Jupiter.

42 The Sun

We explain how you can observe and image the dynamism of our star safely in white light, hydrogen-alpha or calcium-K, whether you have a solar scope or plan to filter a regular instrument.

52 The deep sky

Explore the tools and techniques you'll need to get started in imaging galaxies, globular clusters and nebulae with our deep-sky tutorials.

62 Advanced deep sky

Take your deep-sky imaging further with our tips on using autoguiders, filters, alignment techniques, false-colour palettes and more.

72 Take your astro imaging to the next level

Is your equipment holding you back? Find out how kit upgrades can improve your images.

79 Image processing

80 Solar System objects: basic techniques

Enhance detail and bring out the colour in the planets with our masterclasses on image processing for Solar System objects.

88 Solar System objects: advanced techniques

Return fuzzy stars to bright points, reverse the rotation of planets and bring our neighbours to life in animations with our advanced tips.

96 Deep-sky objects: basic techniques

Stack and blend deep-sky images and say goodbye to light pollution: it's all possible with image editing know-how.

104 Deep-sky objects: advanced techniques

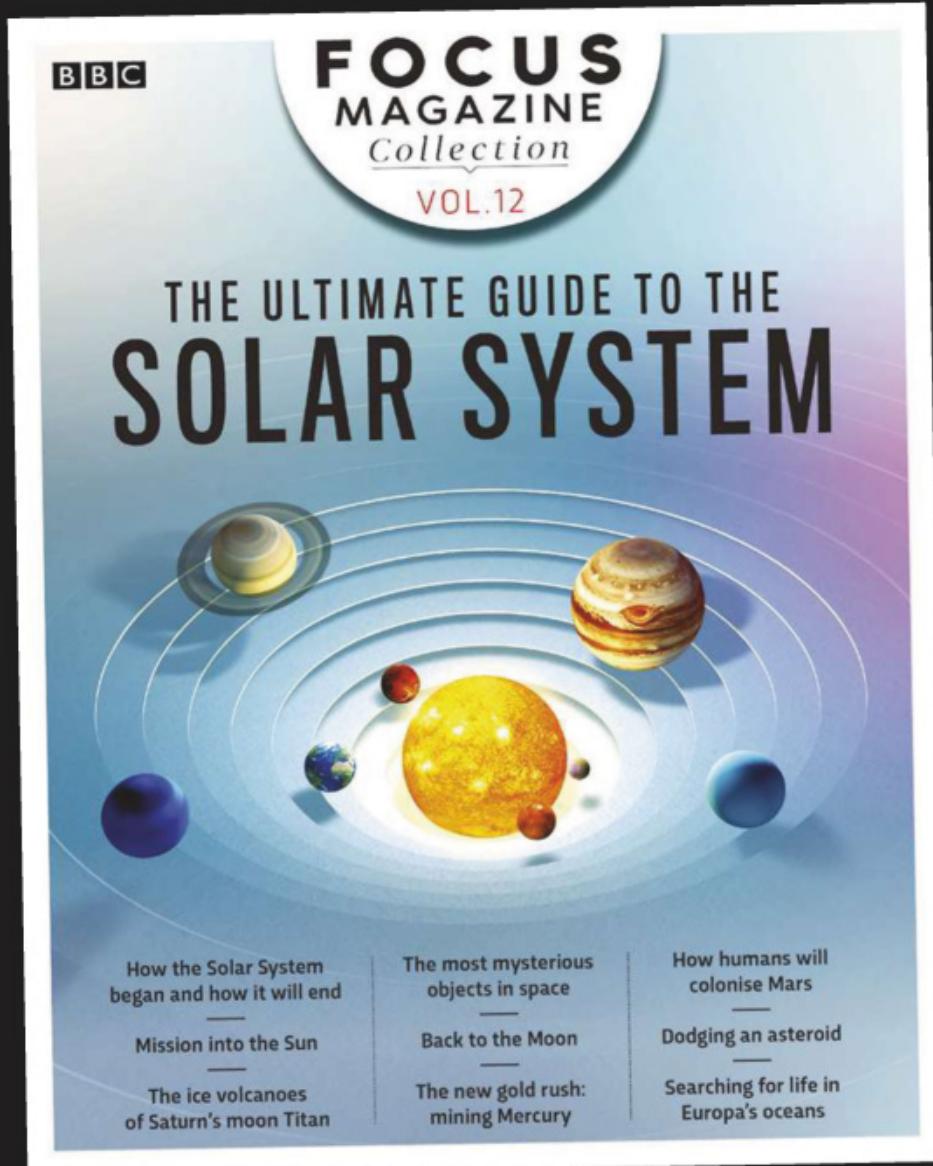
Learn how to shoot calibration frames, process narrowband-filtered images and add extra layers of detail to your deep-sky photos.

114 What to do next

Five things you can do to continue your astrophotography journey.

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ASTROPHOTOGRAPHY

Capturing the night sky for posterity is a gripping passion and thanks to digital technology it's one that has never been easier. That said, it still poses a challenge. The days of wet processing may be long gone, but now there are new camera functions to uncover and much to consider when creating an imaging setup. To make things easier, we've split the astrophotography section

of this special edition into chapters. We begin with nightscapes – images that are similar to the views of the constellations and the Milky Way that you would see with the naked eye. From there we head out into the Solar System, to the Moon, the Sun and the planets, and finally beyond the influence of our star and into the realm of deep-sky objects, such as globular clusters and nebulae. In each

part, we'll outline all your equipment options – what works, what doesn't, what the bare minimum is and what an ideal setup would be – and explain how to use it in the most effective way. For a quick preview, check out the table below to find out what you can expect to capture with your camera. Once you've mastered the art of the capture, you'll be ready to delve into part two: image processing!



WHAT CAN I CAPTURE WITH MY CAMERA?

Camera type	Viable targets
Smartphone	Daylight phenomena and bright twilight scenes; afocal shots of the Moon and bright planets through a telescope, the latest models can now even take basic constellation images
Compact	Daylight phenomena and bright twilight scenes; afocal shots of the Moon and bright planets through a telescope, the latest models can now even take basic constellation images
Prosumer	Daylight phenomena, twilight scenes and some basic night scenes; afocal shots of the Moon and planets; some have limited deep-sky capability for pictures of galaxies, nebulae and star clusters
DSLR/Mirrorless interchangeable lens	All daylight phenomena and night scenes; the Moon through a long lens or attached to a telescope; one-shot-colour deep-sky imaging; basic planetary capability
High frame rate	Optimally suited for Moon, Sun and planets through a telescope; some have basic to intermediate deep-sky capability
Cooled astronomical CCD	Optimally suited for long-exposure deep-sky imaging; capable of imaging the Moon and Sun; basic planetary capability, but good for picking out faint moons



The tips on the following pages will help you capture fabulous shots of the night sky, like this one of the Milky Way



NIGHTSCAPES

A good place to start with astrophotography is by taking 'nightscapes' – wide-field, panoramic images of the heavens encompassing bright stars and the Moon, and perhaps set against a horizon. Nightscapes are particularly good when that great sweep of stars that makes up our own Galaxy, the Milky Way, takes centre stage. Constellations also make great subjects in panoramas.

Your astrophotos can also reveal the movement of Earth by capturing star trails and tracking the changing positions of the planets over time. You don't even have to look beyond Earth's atmosphere as there are meteor showers to watch out for and, depending on the time of year, ethereal noctilucent clouds or the shimmering greens and reds of the striking aurora borealis. ▶

WHAT YOU'LL LEARN

10 Equipment

We walk you through the kit you'll need to capture starry night scenes and twilight phenomena

12 Technique

How to set up your DSLR camera for nightscapes and achieve focus against a dark sky

14 Masterclass 1

Master the tricks of composition and learn how to image bright constellations

16 Masterclass 2

Discover the motion of the night sky in the form of star trails and planetary montages

18 Masterclass 3

Learn how to capture the meteor showers that rain 'shooting stars' down to Earth throughout the year

OUR EXPERTS



Paul Money is *BBC Sky at Night Magazine*'s reviews editor and equipment expert



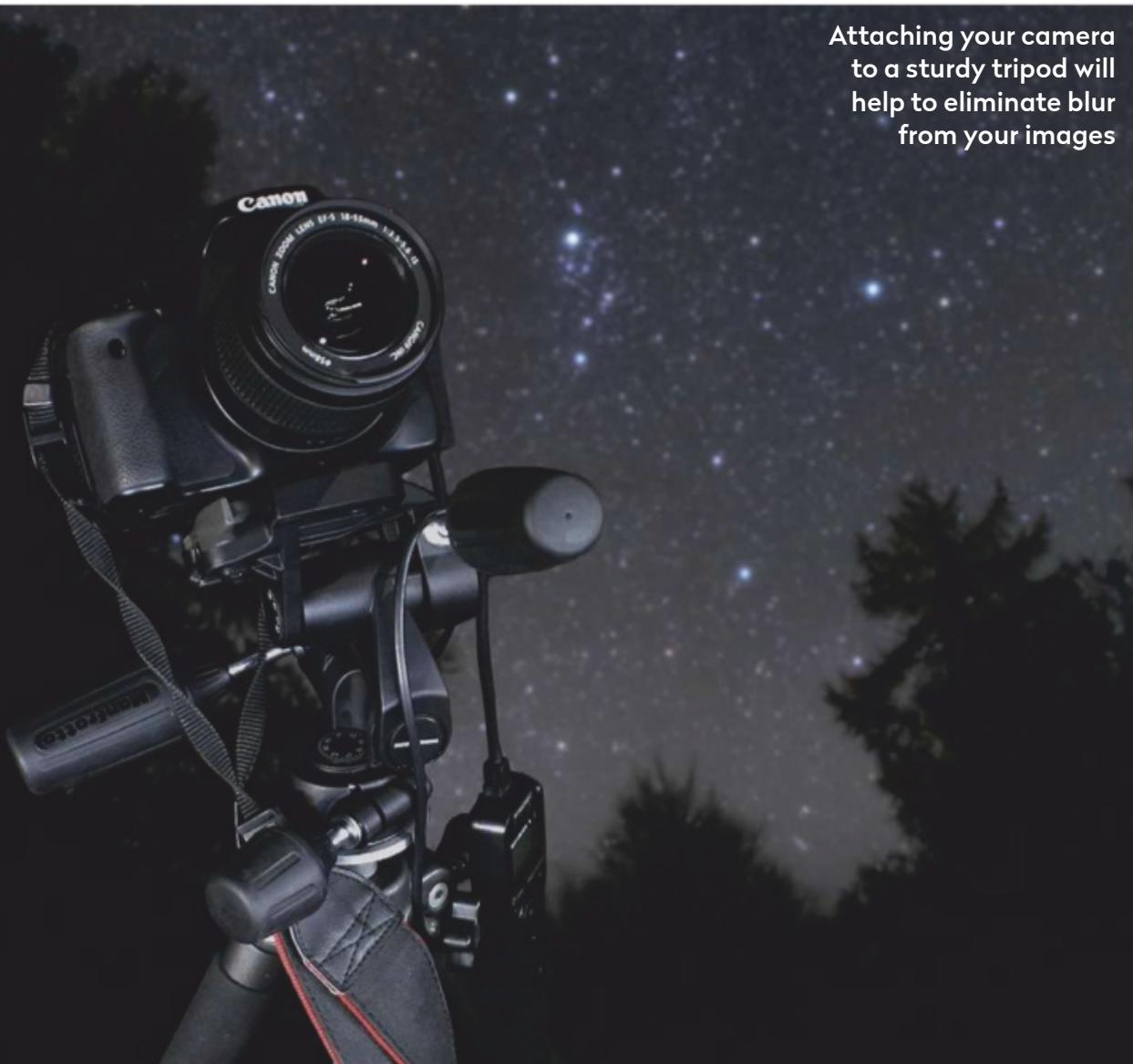
Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

ISTOCK

EQUIPMENT

Essential kit for shooting pin-sharp astrophotos

Attaching your camera to a sturdy tripod will help to eliminate blur from your images



Many of us use a compact camera or smartphone to take everyday pictures, so why not turn them on the night sky? Smartphones can be used for bright twilight subjects such as planetary conjunctions and there are plenty of apps available to help you get the most out of this sort of photography. Today's compacts, on the other hand, can take reasonable images in low-light conditions and some even have manual modes that let you take full control of the camera's functions. The ability to adjust some camera settings for yourself will make for much improved images.

A good example is the Canon PowerShot G1 X Mk III compact. It lets you keep the camera's shutter open to the starlight for up to 30 seconds and its 24.2-megapixel sensor allows for ISO values up to 25,600. Many Nikon and Fuji compact cameras have settings for night portraits, night landscapes and fireworks that can be used to capture limited views of the stars.

WILL GATER, ISTOCK X 5, CANON X 2

Settings like these allow you to capture a wide array of subjects, but there are downsides to compact cameras: they often don't let as much light reach the imaging chip as wider DSLR camera

lenses do and they don't have the flexibility of interchangeable lenses.

DSLRs offer a much wider range of functions and most experienced imagers will have one in their arsenal. DSLRs have the widest range of settings and offer full manual control. They also have interchangeable lenses, so you can swap to a more powerful lens to close in on bright deep-sky objects, such as the Pleiades open cluster in Taurus or the Flame Nebula in Orion. Today's DSLR imaging chips have wide ISO sensitivity ranges, allowing the faint light from many more stars to be recorded for great results. Many DSLRs also have an option to set the shutter speed – the exposure – in increments up to 30 seconds. After that, they'll have a bulb, or 'B', setting that keeps the shutter open as long as the release is pressed for even longer exposures – great for star trails.

Heavenly bodies

Canon and Nikon DSLR bodies stand out for what they offer budding astro imagers. The Canon EOS 4000D, 1300D, 750D and 200D models are all good basic DSLRs for astrophotography. The Nikon D5600, D610 and entry-level D3500 also fit the bill, as does the Sony a68. It's worth noting that DSLR sensors come in two sizes: a smaller format called APS-C (used by all the previously

WHICH DSLR LENS?

There are several DSLR lenses that are useful for astrophotography. Standard DSLR zoom lenses have maximum focal lengths of 50-70mm and can capture the main constellations, brighter sections of the Milky Way and detail within aurorae. To capture the larger constellations or large auroral displays, a wide-angle lens with a focal length of 16-28mm is needed. DSLRs also have high ISO settings compared to film cameras, and you can use these with the higher magnification of 100-500mm focal-length lenses to capture bright stars in asterisms or clusters. If you



can go for fixed-focal-length lenses, all the better: they can be easier to focus than zoom lenses and often have wider aperture settings, enabling more light to get to the sensor.

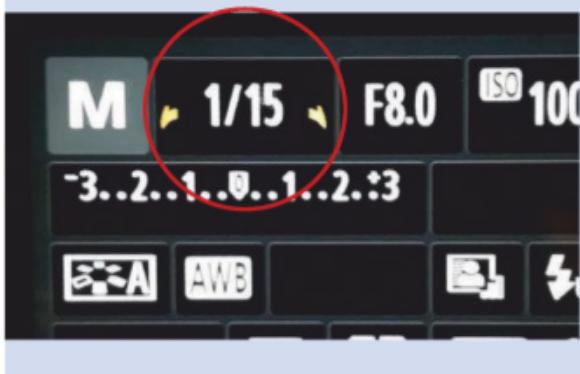
TECH TALK:

Camera settings explained



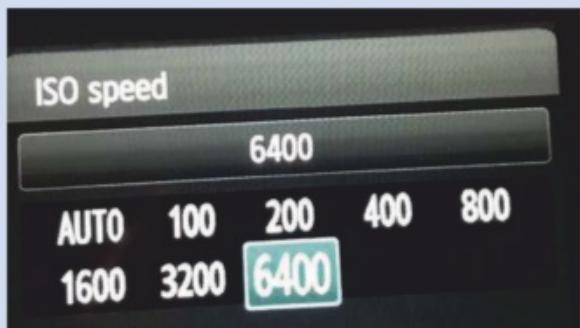
Sensitivity (ISO) ▶

The ISO is an international standard for the sensitivity of the chip in digital cameras. Setting this to a low value like 100 gives high-quality images that need more light; high values like 3,200 let you photograph faint targets, but with a decrease in quality.



◀ Aperture (f/number)

This is the diameter of the lens that allows light to reach the imaging chip. The amount of light let in can be increased or reduced with an iris in the lens – this determines the f/number. A low f/number (such as f/1.8) gives a wider aperture and lets more light in.



◀ Exposure (Shutter speed)

The shutter speed determines how long the imaging chip is exposed to light. The slower the shutter speed, the longer the exposure and the more light strikes the chip. Many cameras offer a mirror lock-up mode to minimise vibrations from the shutter action.

mentioned camera bodies except the D610) and the larger 'full frame', equivalent to the old 35mm film format. In *BBC Sky at Night Magazine*'s tests, the Nikon D700, Canon EOS-1D X and Sony a7S full-frame cameras were found to be worthy of their higher price tags. To take

nightscapes you also need another piece of equipment: a tripod. This will give you the stability to take long exposures without any vibrations affecting the image. Exposures longer than 1/30th of a second will start to lose sharpness and show camera shake – it's almost

"A remote shutter release can make a big difference between taking a shaky picture and a shot with pin-sharp stars"

impossible to hold a camera steady by hand for long periods. Sturdy tripods are best, even if they're more expensive, as lightweight tripods can tremble in the breeze and spoil any nightscapes you take. Brands to consider include SLIK, Manfrotto and Gitzo.

Even with your camera mounted on a sturdy tripod, simply pressing the shutter release button is enough to rattle the whole setup and cause your image to blur, so you'll also need a remote shutter release control. One of these devices, either mechanical or digital, can make a big difference between taking a shaky picture and a shot with pin-sharp stars.

Finally, don't forget that using a white-light torch will ruin your night vision, which takes at least 30 minutes to build up. Use a red-light torch instead, as this sort of illumination won't affect your eyes' adaptation to the dark.

WHICH SETTINGS SHOULD YOU USE?



Constellations

Exposure: 15 to 40 seconds
Aperture: f/2 to f/2.8
Sensitivity: ISO 800 to 1600



Twilight landscapes

Exposure: 1 to 10 seconds
Aperture: f/2.8 to f/5.6
Sensitivity: ISO 100



Aurorae

Exposure: 3 to 30 seconds
Aperture: f/2 to f/2.8
Sensitivity: ISO 400

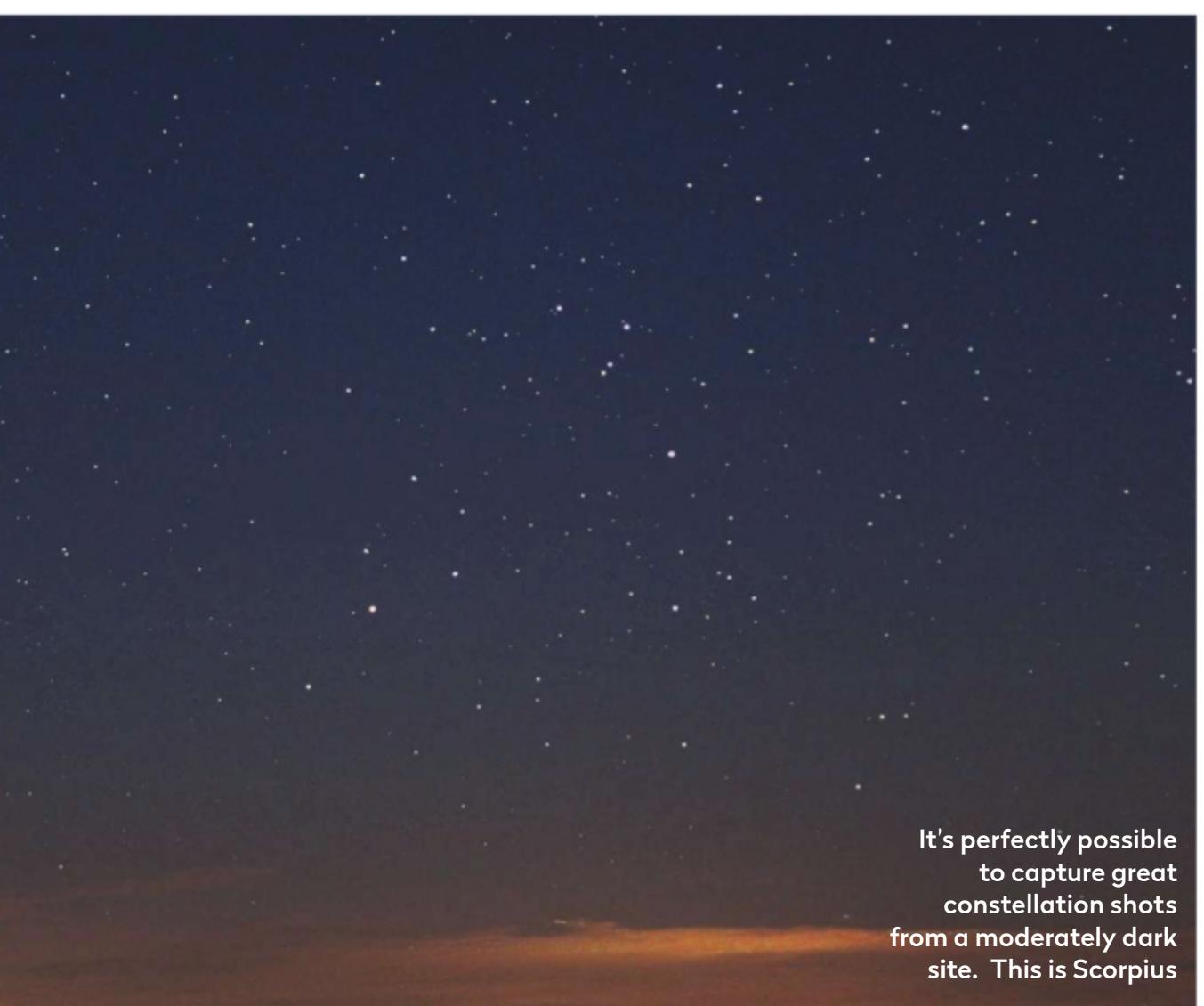


Star trails

Exposure: 5 to 60 minutes
Aperture: f/4 to f/11
Sensitivity: ISO 100

TECHNIQUE

Master your camera's settings to capture the stars



SLRs are particularly good cameras for astro imaging because of the amount of manual control they provide. Thanks to interchangeable lenses they offer a wide range of magnifications – from what you can see with the naked eye to views similar to those through binoculars. Their ability to take long exposures at high ISO values means that DSLRs can also capture images of the Milky Way that you couldn't see with your eyes. This is because when light reaches your eye, your retina immediately sends signals to your brain. With a long exposure, however, light can build up on a camera's sensor before the shutter closes again.

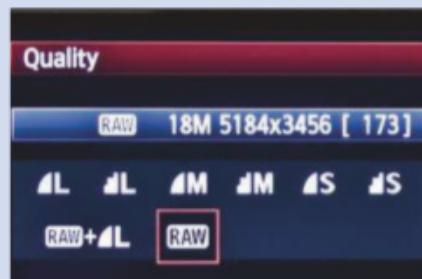
But you need to make use of the manual control a DSLR offers to get the best results, as the built-in autofocus settings aren't so good for capturing the night sky. Autofocus settings can be useful if you're imaging in twilight (to catch Venus, Mercury or a low crescent Moon, for example) as there may be enough light for them to work. But in the dark of night, autofocus struggles to

STEP BY STEP: Set up your DSLR for astrophotography



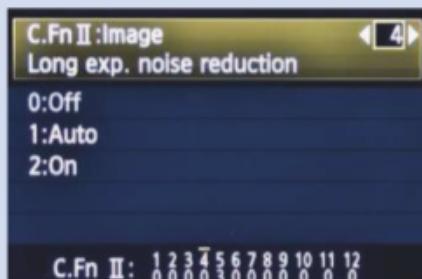
1 Bulb

The bulb setting allows you to control the length of exposures. It lets you take shots lasting from one second up to several minutes, using a remote shutter release or the delayed timer. Such a wide range of exposures can be exploited in your shots – stars can be made to look like pinpricks with a short exposure, or trails with a longer one.



2 File format

Many cameras come with a range of file format settings for your pictures, including Raw, JPEG and Raw+JPEG. Get to know your camera's file formats and ideally use the Raw setting. While this will produce the highest quality results, the larger file size means that any given memory card won't be able to hold as many Raw image files as JPEGs.



3 Noise reduction

This facility is built into many digital cameras and should be used carefully. When taking pictures with a lot of light, such as twilight scenes, noise reduction can improve the shot by cutting out artefacts generated by the camera's sensor. But it can remove fainter stars from images of stars and constellations. If you're shooting these, it's best turned off.



4 Picture styles

This is another facility that has to be used with caution. Many DSLRs let you alter settings such as contrast, sharpness and colour saturation, and save the alterations as a user-defined setting. Subtle adjustments made here can enhance your images, but it's easy to alter a picture too much. The default settings are often the best to begin with.

PRO POINTER:

How to focus for pin-sharp results

While focusing in the daytime is easy, focusing at night is a completely different matter. Autofocus relies on contrast, so the dark sky, coupled with the faint and point-like nature of stars, means that a DSLR's autofocus will struggle to find anything to lock on to. Squinting through the camera's viewfinder won't help much either as it's often only the brightest stars that will be visible and those tiny points

won't be enough to manually focus on. Compact cameras don't find focusing in the dark any easier. The zoom lenses on some models focus past infinity, making it difficult to bring the view to sharp resolution. Most manual fixed lenses for DSLRs can be set at infinity, but it's often not where you'll find the best focus. Here are some tips and tricks to help you do so.



Live view

Most DSLR cameras have a live view screen that shows you what you'd see through the viewfinder. The live view is often magnified and you'll usually be able to angle the screen to a more comfortable viewing position, which are real benefits for shooting twilight scenes, as well as the constellations, the planets and the Moon.



Magnified finders

These can be bought for most brands of DSLR. You attach them to the camera's viewfinder and their right-angle design makes viewing more comfortable. The 2x magnification will help you to judge focus a lot better on brighter stars. Take a test exposure to confirm if the shot is in focus and then adjust the focus again, if needed.



Camera control

For autofocus to work it needs a strong light source to lock on to – most night-sky objects are too faint for this. Aiming at a distant streetlight or the Moon can help it find something to fix on. Once you've found focus, turn off the autofocus and don't touch the lens, otherwise you risk knocking it out of focus again.

Get your camera's settings right and you can reveal the full glory of the Milky Way

cope with the lack of light. Learn to manually control your DSLR's ISO, exposure and lens aperture settings, though, and you'll quickly figure out how to get the best results in the dark.

The best way to start is to bracket your exposures: take a range of different exposure lengths at various ISO values to see which combination produces an image with the best balance between sky darkness and star brightness. Try exposing for five seconds either side of an initial exposure of 15-20 seconds.

Add brackets

Attach your camera to a tripod and plug in the remote shutter release (or use the delayed timer setting if you don't have one). From a moderately dark site, you can get a good picture of a constellation such as Leo with a 50mm focal-length lens by setting the ISO to 400 and the exposure to 15 seconds (use the bulb setting if the long-exposure range is

limited). Set the aperture as wide as it will go – look for f/1.8 or even f/1.4. Focusing on stars can be tricky, but there are ways around this, see 'Pro Pointer' above. Once you've taken the image, check it for elongated stars. If there is star trailing, take another picture with the same settings but reduce the exposure to 10 seconds. If you have a camera with an APS-C sensor, such as the Canon EOS 1300D, star trailing can become more obvious and you may need shorter exposures. These sensors only see the central area of the image projected by the lens, and the final image appears magnified compared to the same lens used with a full-frame sensor.

Another good tip is to take a few pictures with the lens cap on. This gives you 'dark frames', in which the only data is the noise of the sensor itself. This noise can then be subtracted from your final image with photo-editing software. Read more about this on page 106.

MASTERCLASS 1

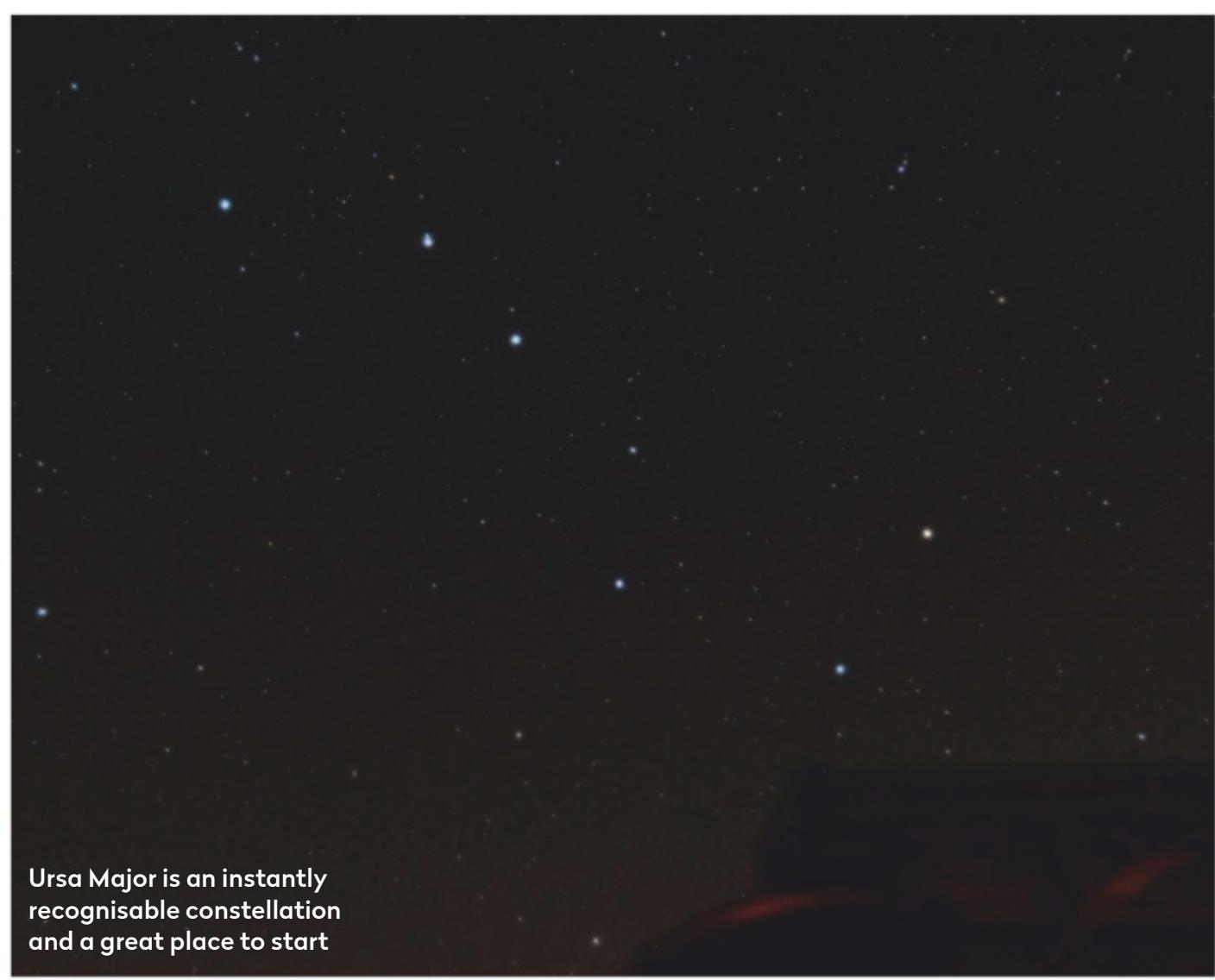
Compose a view of a constellation and capture it

The night sky is full of patterns, constellations of stars that have helped civilisations from the ancient Greeks and Romans to the Aboriginal Australians find their way around the heavens. Photographing them is a great way to start taking astrophotos – you'll capture some captivating images and get your bearings at the same time.

It's not just constellations that make recognisable patterns in the sky. Asterisms, such as the Plough in Ursa Major, also make good, identifiable photo subjects. These familiar groups typically consist of the brightest stars in a constellation and miss out the fainter stars that make up its main shape. Another one to look for is the Sickle in Leo, which looks like a back-to-front question mark. The swarm of stars that is the Milky Way makes for a good target too, especially during the summer and early autumn, when the band of our Galaxy cuts across the night sky.

When they're high in the sky, the constellations are ideal if you're after

ISTOCK X 4, PAUL MONEY



Ursa Major is an instantly recognisable constellation and a great place to start

STEP BY STEP: Four steps to your first constellation image



1 Choose your subject and position

Choose the constellation you want to photograph and point your camera to frame the subject nicely. To orientate the constellation in the frame for a better composition, you may need to adjust the tripod legs as well as the tripod head, which the camera sits on.



2 Find the sharpest focus

Carefully check the focus using the methods described on page 13, and if you've used autofocus recently, turn it off. Take several test shots and then zoom in on them using the live view screen to judge whether the focus setting you've used has sharpened the stars.



3 Adjust the camera settings manually

Put the camera in manual or 'M' mode, and use the menu to set the ISO and exposure, plus any picture adjustment settings. Make sure you've turned off the flash and that there won't be any automatic noise reduction routines active, which can remove fainter stars.



4 Capture and review images

Take your image using the shutter release cable and review it for sharpness with the zoom function. Consider the brightness of the sky and check whether the stars are trailed. If they are, take another image with a shorter exposure time and open the aperture one f/number wider.

PRO POINTER:

Consider your composition

To make your nightscapes more interesting, include an object in the foreground to complement the star field or constellation behind it. Good things to go for are lone trees, buildings with lit windows, dramatic terrain, telescopes and even people.

Use a red- or white-light torch, or a camera flash, to illuminate the foreground. Combining this with a longer exposure will still reveal the stars. A neat trick is to get one person to appear in several places in the photograph. Give the person a torch, get them to stand still with the torch on and then switch it off while they move to a new position, before turning the torch on again. In the finished photo, they will appear in several places at once. On the other hand, a person walking through the scene with a red light switched on during the exposure creates streaks, which can look quite artistic.

Even a twilight sky can add drama by producing a lighter background sprinkled with stars, enabling you to silhouette a foreground object. Cities and towns taken from a high vantage point can add their own, unique effect to a wide-field view.

There are a few things to avoid, however: nearby streetlights or

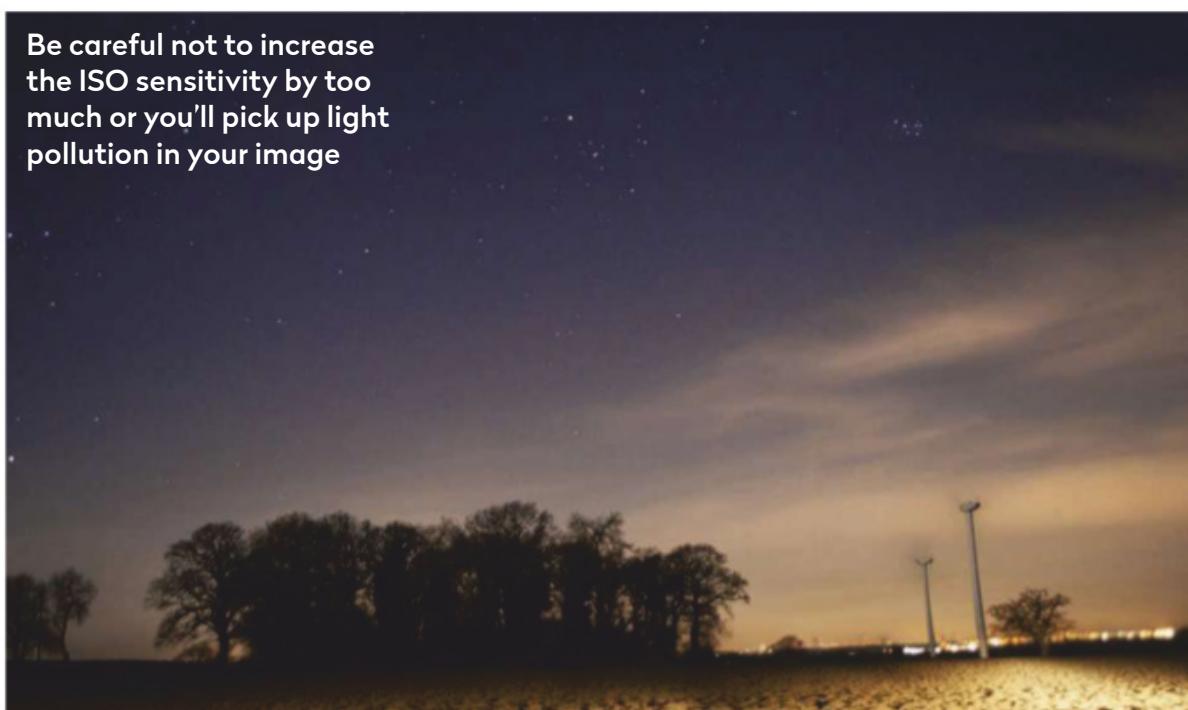


▲ For a nice composition, include a foreground object and apply the rule of thirds

security lights, for example. The light from these can interfere with your image and can create distracting blobs of light known as lens flares. In extreme cases they can even wash out the colour and reduce contrast in your pictures.

The rule of thirds, which divides an image into a grid of nine equal sections, can be useful to for composing a shot. If you're taking an astro landscape, the ground would take up the lower third of the image, drawing your view up to the stars.

Be careful not to increase the ISO sensitivity by too much or you'll pick up light pollution in your image



an uncluttered photograph. But they can also look great when they're near the horizon, either rising or setting. Adding a foreground object into the frame can really enhance the look of your nightscape photos too

– experiment with houses, trees and your surrounding landscape.

Plough straight ahead

So what's the best way to take a picture of the Plough? First, mount your camera

on a tripod and attach the remote shutter release. Then set the aperture to its widest setting (the smallest f/number), choose an ISO setting of 400 and a shutter speed between 10 and 30 seconds. Finally, press the shutter release to take the picture.

If you need to use the bulb setting, use a watch to keep track of the exposure time so you know when to release the shutter. Once you've taken your image, review it on the camera's live view screen, using the zoom function to see whether the stars in the image are sharp. If they look blurry, try making the aperture smaller by one full f/number and increasing the exposure time. To capture more stars you can increase the ISO, but remember that if you're photographing from a light-polluted area, increasing the imaging chip's sensitivity will also increase the amount of orange streetlight glow that's picked up in the photo.

MASTERCLASS 2

How to image star trails and the motion of the night sky



Star trail images are a simple way of revealing the motion of the night sky

MORE INSPIRING TWILIGHT TARGETS



▲ Noctilucent clouds (left) and aurorae (right) are great targets when they appear

We've shown you how to take pictures of constellations and star trails, but there are lots of other interesting targets you can capture using your camera's basic settings and minimal equipment – for example the Northern Lights and noctilucent clouds can be captured with the same settings you'd use for a constellation by adjusting the exposure and ISO to cater for their specific brightness.

Conjunctions of bright planets, when two or more of them appear close together in a twilight sky, are a favourite for many astro imagers. For these scenes, try using your camera's auto settings to see how well they cope. The Moon can also be used creatively. Thirty-second exposures at ISO 400 and f/2.8 during full Moon will look like daylight, but the blue sky will be filled with stars.

The stars in the northern hemisphere appear to rotate anticlockwise around one particular star: mag. +2.1 Polaris (Alpha (α) Ursae Minoris). As this star lies almost exactly on the celestial pole, we call it the Pole Star. Over the course of 24 hours the rest of stars in the sky complete a full circle around Polaris.

If you take a 10-minute, wide-field exposure that includes the Pole Star, you'll see that the stars farther from Polaris have longer trails. The arcs get longer as you move from the pole towards the celestial equator until, at the celestial equator, they're at their longest. South of this plane, the arcs begin to decrease in length again towards the south celestial pole, which for those of us in the northern hemisphere lies below the horizon.

Wide-angle and standard lenses give the best results for star trails. In order to cut down on unwanted light spoiling the view, take your pictures from a dark site.

Using a wide-angle lens with a focal length of 16-28mm, set the aperture to its widest and adjust the ISO to 400. Using your remote shutter release, take exposures of 5, 10, 20 and 30 minutes. These will let you see how star trails grow with longer exposures.

Noise reduction

If the background sky seems too bright in the longer exposures, decrease the sensitivity of the chip by setting the ISO values to 100 or 200. Narrowing the aperture to f/4 or f/5.6 also helps to cut down on the background glow. Very long exposures of three hours or more reveal the circular nature of the sky's rotation, but with digital cameras these will generate excessive noise in the final image, as the imaging chip heats up.

This is one area in which 35mm film still works well, as it doesn't generate any digital noise. With exposures this long, you need to be as far away from light pollution as possible to minimise the amount of orange glow that will be present in your final image.

It's often a case of trial and error to find how long you can expose your shots from any given location before digital noise or light pollution starts to wash out the star trails. If your camera has long-exposure noise reduction, turn this on. And watch out for the clarity of the air. Even small amounts of haze in the atmosphere will produce a bright sky background, shortening how long you can expose for.



Montages of a planet's path across the sky, such as Mars, can be created with Photoshop

PRO POINTER: Montages can reveal planetary progress

The bright, naked-eye planets can also be imaged as points. If you take a photo of the area of sky through which a planet moves over a few months,

you can record its motion. With photo-editing software, it's possible to superimpose images to show the planet's path over the whole period.

1 Subject

Mars, Jupiter, Saturn and Venus make fine targets in a dark sky. To record the movement of the planets over weeks or months you need the planet to be moving steadily, so don't take shots when the planet's apparent motion against the sky is slow.

2 Camera settings

You don't want the stars or planets to trail, so take exposures of 10 to 20 seconds, set the aperture to its widest and select ISO 400. If there's a lot of light pollution set the ISO to a lower value, say 200.

3 Time your shots

For a relatively fast-moving planet such as Mars (Jupiter and Saturn are slower), take images a few days apart. Make sure that your pictures are all of the same star field, framed in the same way. Take note of the brighter stars to help as a reference.

4 Making a montage

In your photo-editing software, use the first image as a base and import the others into separate layers. Set each layer's transparency to 25 per cent so you can rotate and align them with the base, before merging them.

STEP BY STEP: Image star trails in four simple steps



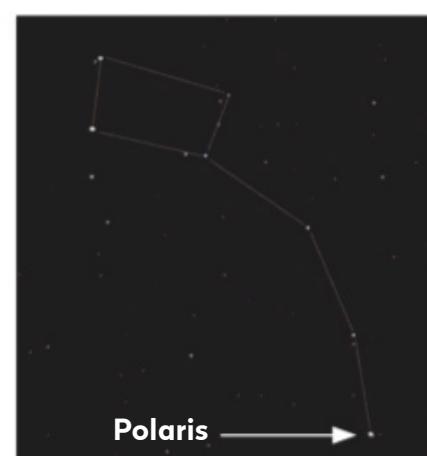
1 Equipment

Select your lens and mount your camera to a tripod. Adjust the tripod legs so they provide a solid base. Attach the remote shutter release so you don't vibrate the camera while you're taking the shot.



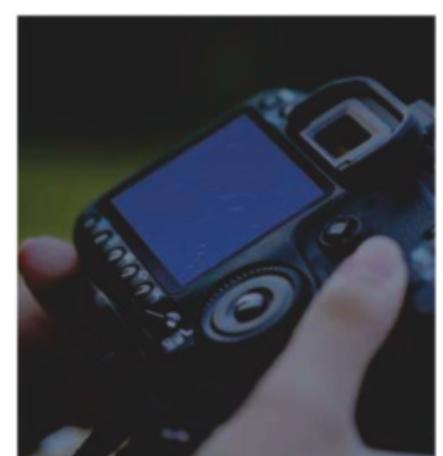
2 Camera settings

Select the ISO, switch the camera to bulb mode so there's no limit to the length of the exposure, then focus. Ensure your flash is disabled and switch on the long-exposure noise reduction.



3 Subject

Decide whether to shoot short star trails near Polaris, or longer trails with a constellation near the celestial equator. Ursa Minor is good for the former while Orion works well for the latter.



4 Capture and review

Take several exposures ranging from five minutes up to half an hour, then review the results. If the sky looks too bright, reduce the ISO and set the aperture to a larger f/number.

MASTERCLASS 3

Make the most of the many annual meteor showers

Meteor photography isn't actually that hard to do. You need plenty of patience but, once set up, the process of catching a meteor on camera is a waiting game – a bit like celestial fishing. There are several prominent showers throughout the year: these include the Lyrids in April, the Perseids in July and August, the Orionids in October, the Leonids in November and the Geminids in December.

The first thing to consider is your camera. As you need good sensitivity, a changeable field of view and longish exposures, a DSLR is the best tool for the job. You'll also need to cover a fairly large part of the sky: opt for a normal photographic lens with a focal length of 18-35mm if you're using a non-full-frame camera, or a focal length of 28-50mm if you're using a full-frame model. The lens needs to be opened fully so that it's set at its lowest f-number: f/2.8 is good, f/2.0 excellent, but f/1.4 is close to perfect. It also needs to be pre-focused at infinity and have autofocus turned off.

The focal length of the lens determines the field of view, with shorter focal lengths delivering the widest. Meteors can appear anywhere in the sky, so you'd think that the best lens would be the one with the shortest focal length, but unfortunately this is not always the case.

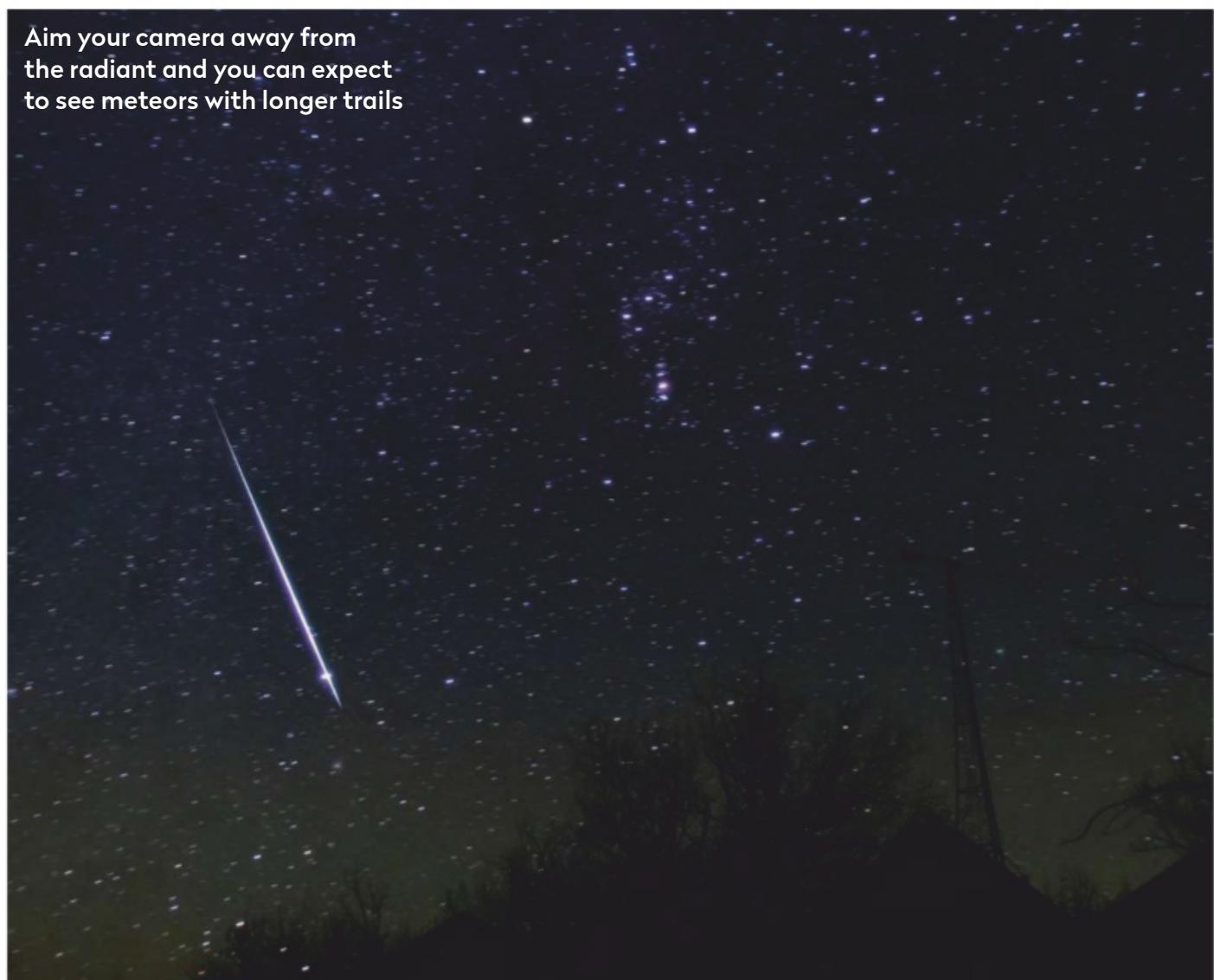
The sad reality is that trails can look a bit puny in really wide-angle shots. On the other hand, a wide-field lens comes into its own if a long-tailed fireball passes through the field of view. In this instance, a lens with a longer focal length may only catch part of the trail.

The simple fact is that a wider lens will catch more meteors than a narrower one, but a narrower lens will typically give better results. This epitomises the main issue with meteor photography: every shot you take is a compromise.

Fine-tune your setup

The camera should be set to be very sensitive, with an ISO value of around 1,600 or 3,200. These higher levels typically generate a fair bit of noise, but will also record more trails. There's no point in capturing an aesthetically

Aim your camera away from the radiant and you can expect to see meteors with longer trails



pleasing image of the sky if you don't record any meteors in it.

When film was used for meteor photography, it was common for astro imagers to use exposures of 10-30 minutes. When using modern digital devices, exposures are best kept relatively short, around 30 seconds. The easiest way to do this is to simply set the exposure time to 30 seconds (the maximum value for most DSLRs) and the shutter mode to continuous. Holding the shutter button down then makes the camera take 30-second exposures, one after the other, until the button is released. A lockable remote shutter release is the simplest way to keep the button depressed.

As far as mounting the camera goes, if you want to keep the same patch of sky in the frame, you'll need to put the camera on a driven equatorial mount, perhaps piggybacked on a telescope. Placing the camera on a fixed tripod works just as well, but in this case the stars will pass through the frame over

time. If you keep your exposures short, they shouldn't noticeably trail.

Finally, you'll need to decide where to point your camera. If you aim it at the shower's radiant, the meteor trails will be short; if you train your lens farther from the radiant, they'll appear longer. One good technique is to place the radiant close to the middle of either of the frame's short edges. This way any shower meteors are travelling along the long edge of the frame, so they're less likely to move out of shot. This perspective also shows you where the meteor trails come from in the sky.

A good rule of thumb is to point the camera so it's aiming about 60° above the horizon. At this angle it's not looking through the murky layers of atmosphere that would dim meteor trails, but still pointing through a thick enough layer so that you see more meteor trails than you would looking directly overhead. Of course, some will pass above you, but as we've said, meteor photography is all about compromise.

STEP BY STEP: How to catch the best images of meteors



1 Narrow or wide-angle?

Use an 18-35mm lens for a non-full-frame DSLR or a 28-50mm lens for a full-frame one, and a lens with the smallest f/number. Remember, wide-angle lenses will cover more sky than narrower ones, but the trails will look less impressive.



2 Tilt and pan or equatorial?

A simple tilt and pan tripod is the easiest way to mount your camera, though a driven equatorial mount will keep it pointing at the same patch of sky. Alternatively, wedge the camera somewhere so that it points at the sky.



3 Find your focus

Set a high ISO – 1,600 or 3,200. The lens should be fully opened (lowest f/number) and pre-focused at infinity with autofocus turned off – the focus needs to be very accurate for meteor work. If your camera has live view focusing, use that.



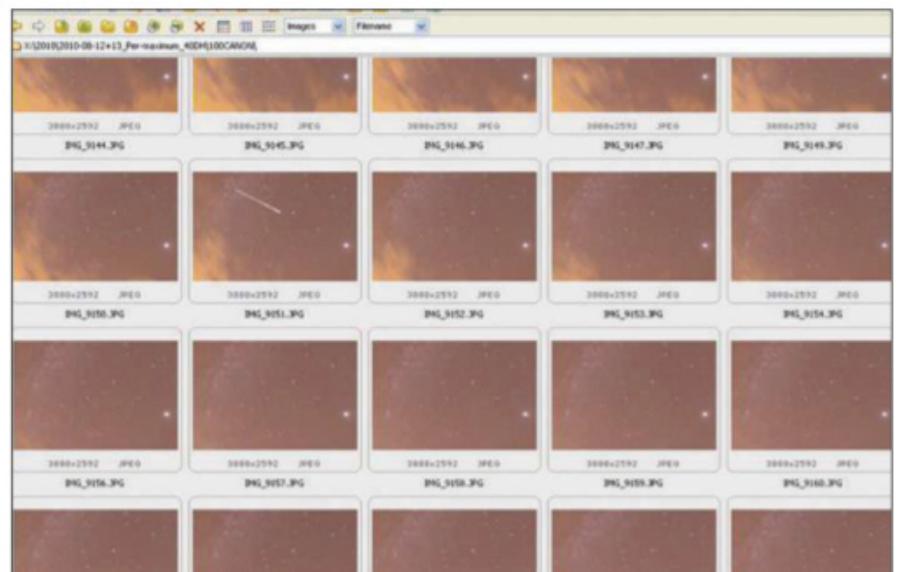
4 Set the shooting mode and exposure

Set the exposure length to 30 seconds and the shooting mode to continuous (marked by the arrow above). Use a lockable remote shutter release to capture consecutive shots – the camera will continue to shoot until you unlock the release.



5 Monitor battery and memory levels

Keep an eye on the state of the battery, how full your memory card is and whether any dew has misted up the lens. Keep spare memory cards, charged batteries and a 12V camping hair-dryer handy – use the latter to remove any dew build up.



6 Check for meteors

Download the images and use an image viewer such as the freeware FastStone (www.faststone.org) to check them for trails. If you spot a trail that persists over two or more shots it may not be a meteor – it's more likely to be a satellite.





► Discover how to create a stunning lunar mosaic like this on the following pages

THE MOON

With its shifting phase and the wobbles of libration bringing myriad new features into view each night, the Moon is a wonderful target for imagers of all abilities. As the largest object in the night sky, as seen from Earth, it's also an obvious place to start when you're learning to image the heavens. But for all its size, proximity and brightness, it takes great attention to detail to

capture top-quality images of Earth's natural satellite. We show you how to do it in this section – starting with the equipment you need and then moving on to the techniques that will help you to capture better lunar shots, whether you're using a DSLR or just a smartphone. If you're stuck for ideas, we also look at six classic lunar sights that everyone should have a go at capturing. ▶

WHAT YOU'LL LEARN

22 Equipment

We explain you what kit you'll need to take great shots of Earth's nearest neighbour

23 Technique

How to plan your shots and capture sharp images, plus six of the best first-time targets

25 Masterclass 1

You really can use the smartphone in your pocket to shoot the Moon – we show you how

26 Masterclass 2

Capture a full-disc shot of the Moon, making use of high-dynamic range imaging techniques

28 Masterclass 3

Shoot and assemble a large composite lunar image with our guide to making mosaics of the Moon

OUR EXPERTS



Will Gater is an astronomer and author who presents live astronomy shows



Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

EQUIPMENT

The kit you'll need to start snapping the Moon

The great thing about the Moon is that anyone with a telescope and either a smartphone or a compact camera can take a decent image of it – all you need to do is hold your camera up to the telescope's eyepiece and start snapping away. This technique is known as 'afocal photography' and if you already have a camera and telescope, you don't need anything else to get started.

A DSLR provides you with several options. They can be used to take afocal shots, just like smartphone and point-and-shoot cameras. Or they can be turned directly to the night sky to capture nightscapes (see page 8) with the Moon at centre stage. Although, bear in mind that the Moon will appear small in such an image taken with an APS-C camera's standard 18-55mm lens. To increase the size of the Moon's disc in your images and reveal more detail on its surface, you'll need a longer focal length lens. A lens with a focal length of 300mm or more will show the lunar seas as well as some of the more prominent craters and mountains.

The fact that DSLRs have detachable lenses means that they can also be connected directly to a telescope, essentially turning the telescope into the camera lens. To do this you'll need a T-adaptor and a T-ring. The T-ring is

brand-specific. It mounts on your DSLR and screws into the T-adapter, which then attaches to your telescope.

Although the newest models of DSLRs can shoot video, they're not ideal for high-resolution lunar imaging, and this is where high frame rate planetary cameras come in. These cameras are capable of taking short videos and shoot many frames per second. You can use any telescope you like, although large aperture Schmidt-Cassegrains and Maksutov-Cassegrains are popular choices with top lunar photographers. This is because their longer focal lengths are well suited to close-up imaging of the Moon, and compared to a high-quality refractor telescope you get a much larger aperture for your money.

Whatever type of telescope you use, make sure it's well collimated, by ensuring that its optics are carefully aligned to produce the sharpest image possible. Your telescope's instruction manual will show you how to do this. As in any area of astronomy, your telescope's mount needs to be rock solid and stable. The ability to track the Moon – either with a motor drive or with full Go-To capability – is a must if you're using a high frame rate camera. A mount's drives should be set to track at the lunar rate, not at the rate the stars



▲ Tools of the trade: a telescope and mount, a compact camera, a high frame rate camera, a laptop and a digiscoping bracket for afocal photography

move across the sky. If you're using a Go-To mount, take time to set it up properly, otherwise you may find yourself having to make continuous, tiresome tracking adjustments when imaging. If you're using a high frame rate camera you'll need a computer to run it. This computer will also need capture software installed if your camera doesn't have any of its own.

TECH TALK: Essential accessories



Red filter

If you're using a monochromatic planetary camera you might find it helpful to fit a red filter when capturing lunar images. Using one can help produce a crisper final picture.



Barlow lens

A must for detailed close-ups of the lunar surface and its craters, whatever camera you use. It increases the focal length and the magnification of your system, typically by two or three times.



Smartphone bracket

Holding a smartphone squarely over an eyepiece while you take a photo is a delicate art. You can make things easier with a dedicated bracket to do the job for you.

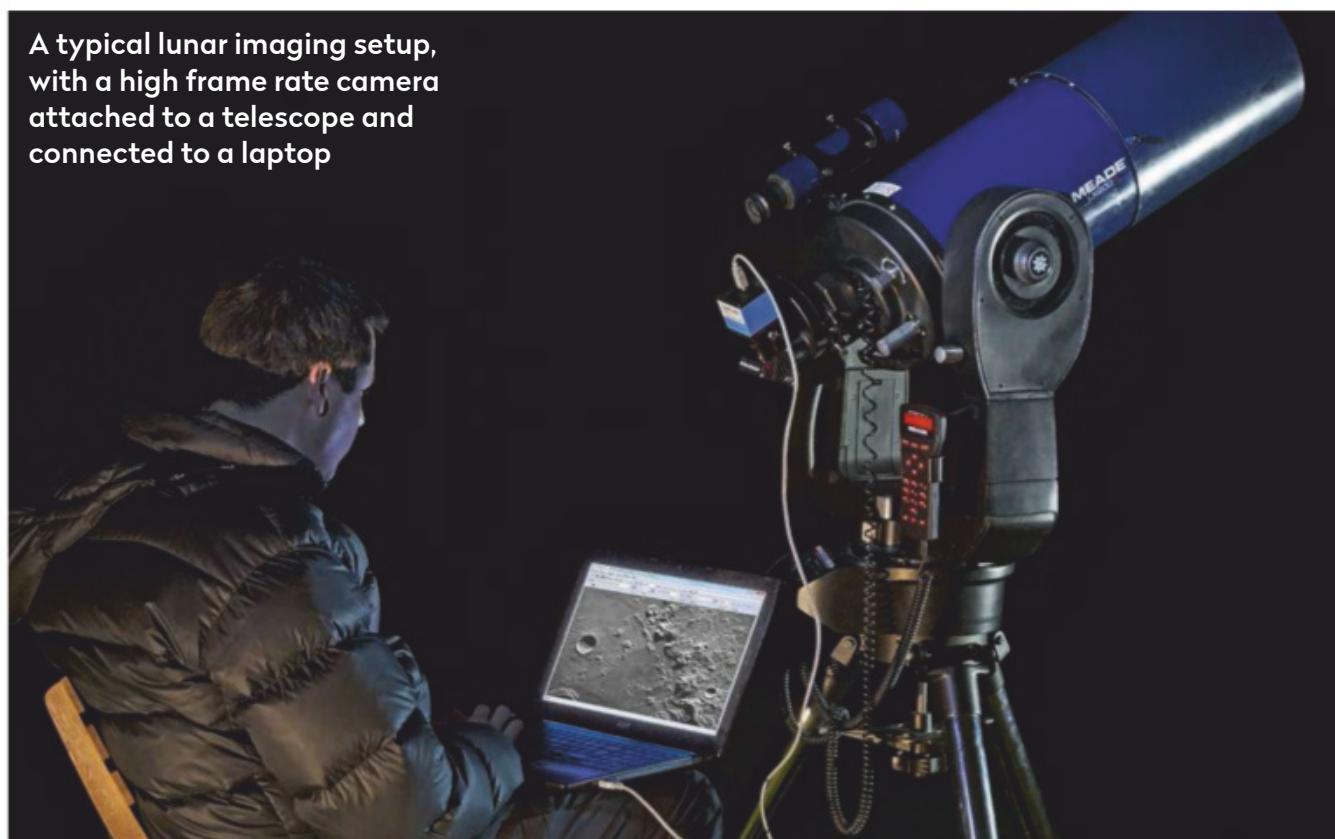
TECHNIQUE

These tips and tricks will help you get the perfect shot

The first step when setting out to image features on the Moon is to decide what your target is and work out the best time to capture it. There are various apps and programs that can help you to do this – a few of our favourites are listed on the next page (see 'Planning tools').

To reveal intricate surface textures and the rugged nature of the lunar crust, it's best to take your shots when your target is lit from an angle. This will be when it's located near the line between the light and dark sides of the Moon – known as the terminator. This is particularly important when capturing very small craterlets and other subtle lunar features such as rilles; when they're illuminated from above, they can be practically invisible.

A typical lunar imaging setup, with a high frame rate camera attached to a telescope and connected to a laptop



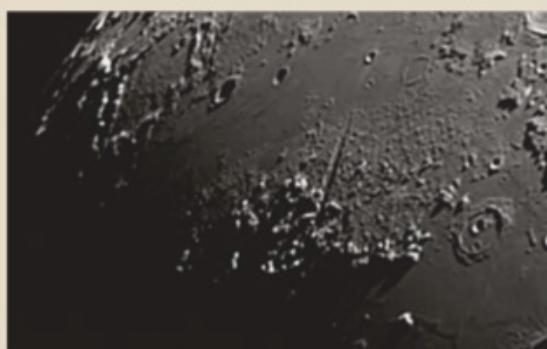
TECH TALK: Why video still trumps imaging

It sounds counter-intuitive, but to end up with a high-resolution close-up of the lunar surface it is better to record a video than take stills. Why is this?

The answer doesn't lie out in space but closer to home, in Earth's atmosphere. When looking at the Moon at high magnification on an average night, you'll notice the view undulating, with moments of steady, sharp views and then brief blurred instants. Since they generally only take single still images, the shots from a DSLR or point-and-shoot camera risk being blurred by this atmospheric turbulence at the

moment when the shutter fires. A short video taken with a webcam or planetary camera, recorded in the AVI format, has many frames each second. It enables the sharpest moments of clarity to be selected.

You can then stack these frames together using specialised software and process them further to bring out tremendous detail on the Moon's surface. So for wide-field shots of the Moon, DSLRs are fine. But when it comes to high-resolution close-ups of its mountains and craters, it's the dedicated planetary cameras that come up trumps.



▲ A single frame from an AVI of the Moon's Vallis Alpes, left, and the final stacked image, made up of 720 frames, right

Atmospheric turbulence can also blur and distort your view of the Moon, in a similar way to how heat haze rising from a road on a hot day can distort your vision. The extent to which the view is undulating is known as the 'seeing'. If the view is mostly steady, without much turbulence, the seeing is said to be good. Good seeing is what you need to capture the sharpest lunar images.

You can't control the seeing conditions, but there are other things you can do to improve the view. One is to leave your telescope outside to cool down to the ambient temperature before you start imaging. This will reduce the amount of wobbling in your image caused by heat rising in and around your telescope. For similar reasons you should never take images from indoors looking out, either through a window, skylight or near a doorway. Heat escaping from the house will cause the view to shimmer wildly, making high-resolution imaging very difficult.

Once you've set your telescope up and left it to cool down for about an hour or so, you can connect your computer equipment and start imaging. If you need to make minor corrections to the tracking on your Go-To or driven mount while imaging, be sure you know which button to press on the ▶

► hand controller to move the image on screen in the direction you actually want. You can check this by rotating the camera in the eyepiece holder so that when you press the left or up button, for example, the image does indeed move left or up.

If you're using a camera with a monochrome chip and the seeing conditions aren't perfect, it's a good idea to use a red filter on the camera. Red wavelengths of light are less affected by poor seeing, so using a red filter should improve the view.

This is also the time to make sure your capture software is set up correctly and is recording to a hard drive with sufficient free space. Record each night's captures to a fresh folder so they can be easily located later on. Most capture software will have a live window that shows you the view the camera is seeing. This is crucial when it comes to focusing.

To focus the camera, make sure it's securely locked in the eyepiece holder – you don't want it to move out of focus as you're imaging. Then, pointing the

telescope at the Moon's terminator, adjust the focus knob. The high contrast between light and dark at the terminator makes it easy to judge when the image is at its sharpest. You can then move the

telescope to your target, knowing it's in focus. Once you're ready to image, take a short video of just over a minute. At 15fps (frames per second) this should give you more than 900 frames to sift through.

PLANNING TOOLS

The best free apps and software for lunar imaging

Moon Globe



This great free app can be used on your iPhone, iPod

Touch or iPad. It shows what the Moon looks like for a given date and time, complete with shadow details.

[Via iTunes App Store](#)



Stellarium

This free planetarium software is handy for working out where the Moon will be. It's great for when you're planning a long night of imaging to create a lunar mosaic.

stellarium.org



Virtual Moon Atlas

An authoritative piece of freeware for planning your observations in detail using an interactive atlas and feature-rich information panel.

ap-i.net/avl/en/start

PRO POINTER: Six top first-time targets

Crater Clavius

This is a great target if you're trying to push your equipment to its limit. See how many of the small craterlets on the crater floor you can capture.



Rupes Recta

Also known as the 'Straight Wall', Rupes Recta is an enormous fault on the lunar surface. The trick is to catch it under the right illumination to see it clearly.



STEVE MARSH X 6, PAUL MONEY X 3, PETE LAWRENCE

Crater Copernicus

Being one of the most stunning craters on the Moon, Copernicus is a wonderful imaging target. See if you can capture its magnificent terraced walls.



Vallis Alpes

This valley cuts straight through the lunar Alps. The challenge here is to see if you can capture the elusive rille that runs all the way along its length.



Montes Apenninus

This chain of peaks is one of the great lunar mountain ranges and a good target for afocal photography. It stretches 600km across the Moon's surface.



Crater Tycho

Crater Tycho is surrounded by ejecta rays – brighter material that was flung out by the impact that formed the crater. It has a huge peak at its centre.



MASTERCLASS 1

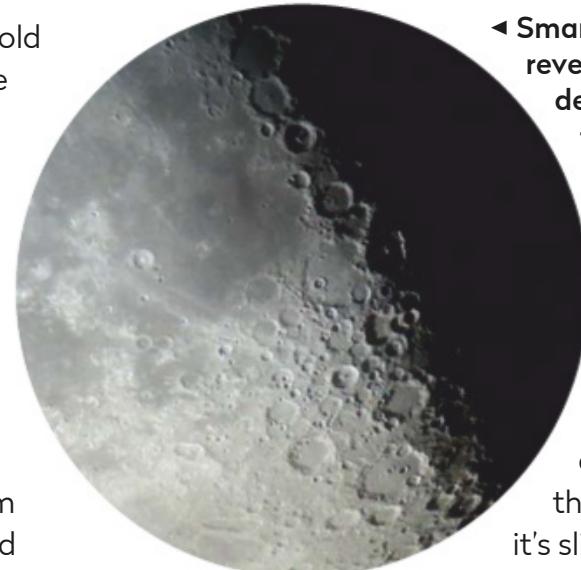
Afocal imaging with a smartphone

Many of us carry around smartphones that have cameras built into them. The first of these were good for quick, spur of the moment shots, but as their imaging technology has matured, the capability of smartphone optics has increased to a point where they can rival some quite decent point-and-shoot cameras. We're going to prove that by showing you how to use a smartphone to take images of the Moon with afocal imaging, the technical term for simply aiming your smartphone's camera down your telescope's eyepiece. There are two ways to do this: one is to simply hold your phone's camera over the eyepiece, the other is to use a smartphone adaptor, which attaches to your telescope's eyepiece to provide greater stability.

You wouldn't think it would be difficult to point a smartphone camera down the eyepiece of a telescope, but there are techniques that need to be mastered. You'll need to hold the phone squarely over the eyepiece and keep it steady without touching the telescope. Once you've got this bit right, the tricky part is pressing the shutter button without moving the phone. Be prepared for some mediocre shots at first but persevere – they will get better.

Whether you hold your phone or use an adaptor, you'll have to set your telescope up with an eyepiece, ideally one with a low to medium magnification to start with – 25mm is normally a good choice. If you're using a short focal length telescope with a low-power eyepiece, you should be able to get a shot of the Moon with the telescope on a fixed tripod. A driven and polar-aligned equatorial mount makes things easier, keeping the Moon centred and allowing you to use higher magnifications without your images suffering from motion blur.

Point the telescope at the Moon and focus the view through the eyepiece. With the Moon centred in view, hold your smartphone so it's pointing squarely down the eyepiece. Try not to touch the eyepiece as this may move the telescope, nudging the moon out of view. Once you've got the Moon on the phone's screen, check that the camera



◀ Smartphone images still reveal fantastic lunar detail, especially along the terminator

lens is looking squarely down the eyepiece. If you get it right, the light from the eyepiece will be at its brightest and evenly spread as it enters the phone's camera lens. If it's slightly tilted, you'll get a gradual degradation of brightness across the image. When you're all lined up, take the shot. Be gentle, though, as it's easy to move the phone as you press the shutter button. Some smartphone earphones can be used to operate the shutter via their in-line volume controls, while others offer voice control to prevent movement at this crucial moment. For extra stability, a smartphone adaptor can take the strain out of holding your smartphone so are well worth your consideration.

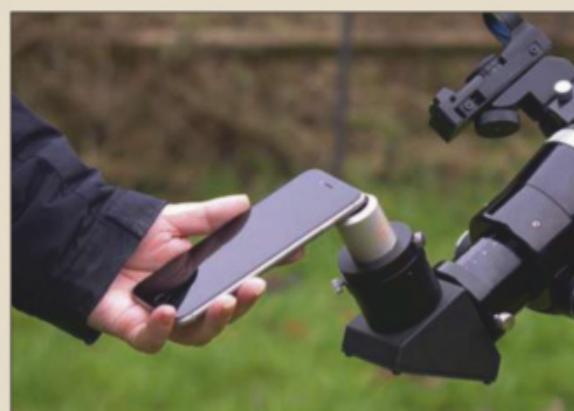
Modern smartphone cameras are starting to offer more ways of altering exposure, often by photo apps. But the Moon should be bright enough to trigger your phone's autoexposure functions so that the shot comes out correctly.

STEP BY STEP: Use your smartphone to shoot the Moon



1 Prepare

Anticipate the Moon's movement and point your telescope just ahead of it in the sky (you'll take the shot when the Moon becomes centred). Focus the scope as accurately as you can, making sure the features on view are sharp.



2 Line up and shoot

Hold the phone squarely to the eyepiece until you get a bright blob on the screen. Carefully alter the distance between camera and eyepiece until the view focuses and isn't overexposed. With the image on the screen, take the shot.



3 Use a smartphone adaptor

A smartphone adaptor takes the strain out of holding your phone and keeping it lined up. Once attached it can be adjusted until the smartphone lens is lined up with the eyepiece. Once aligned, you can take the shot.

MASTERCLASS 2

The crescent Moon and earthshine

Blending the seam between the crescent and the earthshine is the trick to producing images like this



For this masterclass, we're going to show you how to capture a full-disc shot of the crescent Moon, along with its accompanying earthshine, using a DSLR camera. The image we're aiming for, like the one above, depicts the Moon with a slim edge illuminated by light directly from the Sun and the rest of its face dimly lit by light reflecting off Earth.

As is often the case with astrophotography targets, it involves more than simply pointing your camera up at the sky on the appropriate night and pressing the shutter release. But before we explain how to catch a shot like this, it's worth explaining how this elegant scene comes about.

At the point of new Moon, the lunar disc lines up with the Sun, while appearing slightly above or below it in the sky. In this position, the Sun's light is only able to reach the far side of the Moon directly, so the lunar face (the side seen by us on Earth) is bathed in darkness. It's not possible to see the

Moon at this point in its monthly cycle as it is lost to the Sun's glare.

In the days following new Moon, the Moon appears to gradually separate from the Sun. As the Moon slowly moves eastwards and its separation from the Sun increases, more of the Sun's light is able to creep around its edges and we get to see more of its face illuminated with each passing night. This process is what gives us the Moon's familiar phases, starting with the new Moon, followed by the crescent Moon, then the first quarter and the gibbous phases, before reaching the full Moon phase, when it's opposite the Sun in the sky. The sequence then plays out in reverse, before reaching the next new Moon, 29.5 days later.

During this cycle we can often see the dimly illuminated portions of the Moon thanks to earthshine but the contrast between the portions is perhaps most dramatic during the crescent phase. Imaging the earthshine is pretty

straightforward: you use a longer exposure than for the crescent. This overexposes the crescent but will bring out detail on the earthshine-lit portion.

If you were to capture an image exposed for the crescent and another for the earthshine, you'd think that they would line up and produce a view similar to that which you'd see with the naked eye. But achieving this can be difficult. The human eye has an amazing dynamic range. When you look at a thin crescent Moon with the glow of earthshine, it's easy to take for granted just how much work your eyes are doing to see both the crescent and the earthshine so naturally.

A camera will struggle to see this contrast in one image: you'll need to combine two exposures. This technique, known as high-dynamic-range imaging, is a key astrophotographic skill that can help with tricky targets such as this. The steps opposite will help you capture the necessary shots and blend them.

STEP BY STEP: Shooting and processing to capture a crescent Moon



1 Attach your camera

Attach your DSLR to a telescope or lens with a focal length of at least 300mm – this will give you a large enough image to see the Moon's disc with some detail on it. A telescope or lens with a focal length of around 1,000mm is ideal.



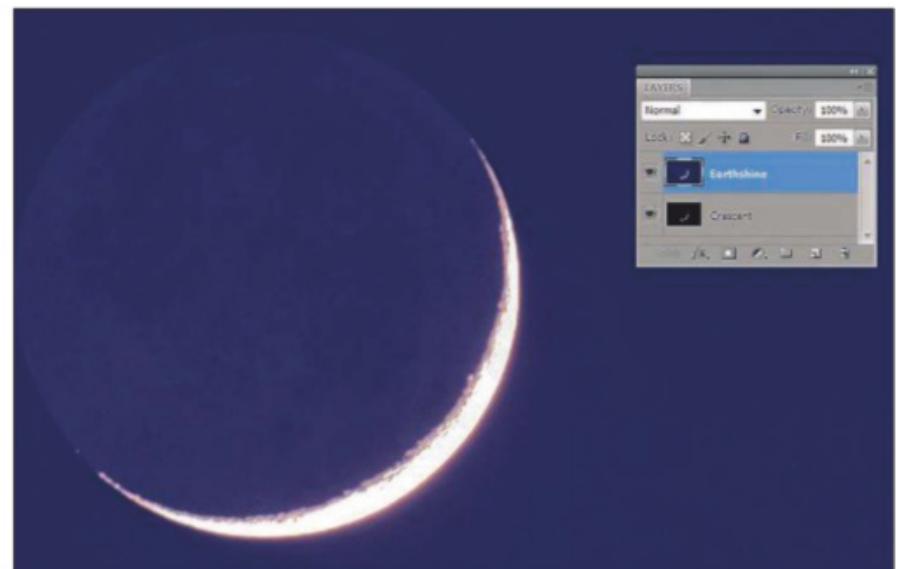
2 Set the ISO

Focus the camera as accurately as possible and set an ISO of 200-400 for the crescent shot. The exposure you'll need will depend on your equipment. Take a test shot of 0.5 seconds and review the result.



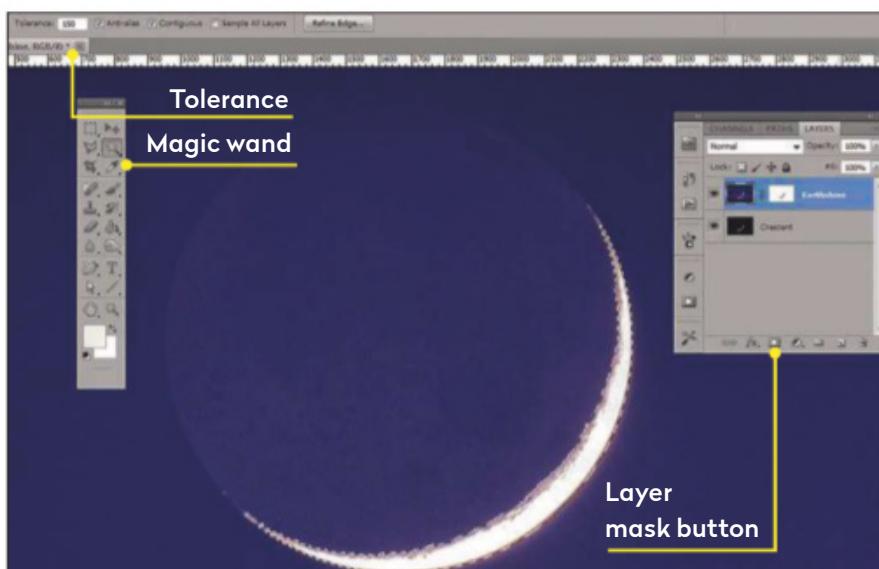
3 Adjust exposure

Adjust the exposure so that the crescent comes out bright but without any white in it: check by looking at the image's histogram on your DSLR. Take several shots increasing the exposure as you go until the image looks really overexposed.



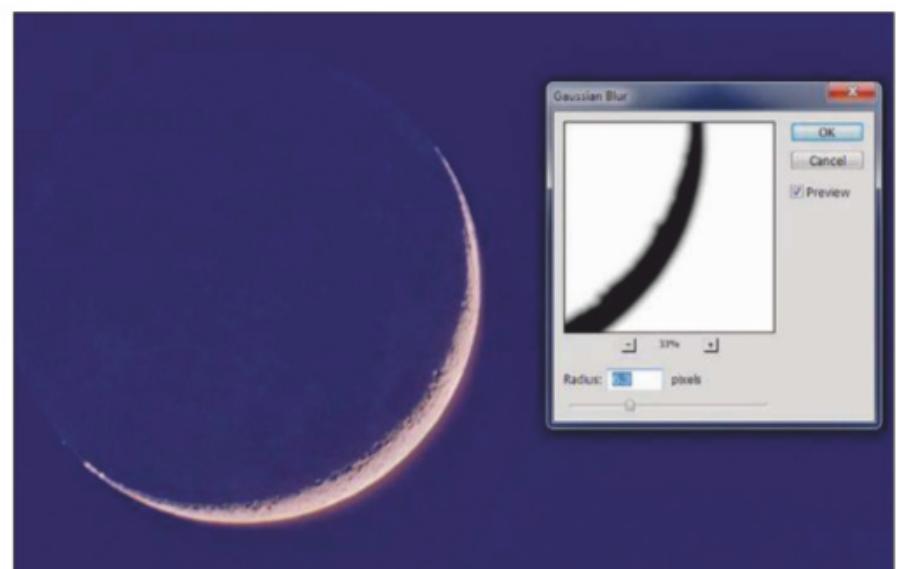
4 Layer up

Pick the best crescent shot and open it in Photoshop or GIMP. Then pick a sharp overexposed shot of the earthshine without too much glare from the crescent. Load it as a new layer and align the two – reduce the opacity of the upper layer to do this.



5 Magic maske

Make the upper layer opaque, then use the magic wand tool to select the crescent (adjust the tolerance if it's not selecting it all). Create a layer mask. In Photoshop, copy the selection, hold down the alt key and click the layer mask button.

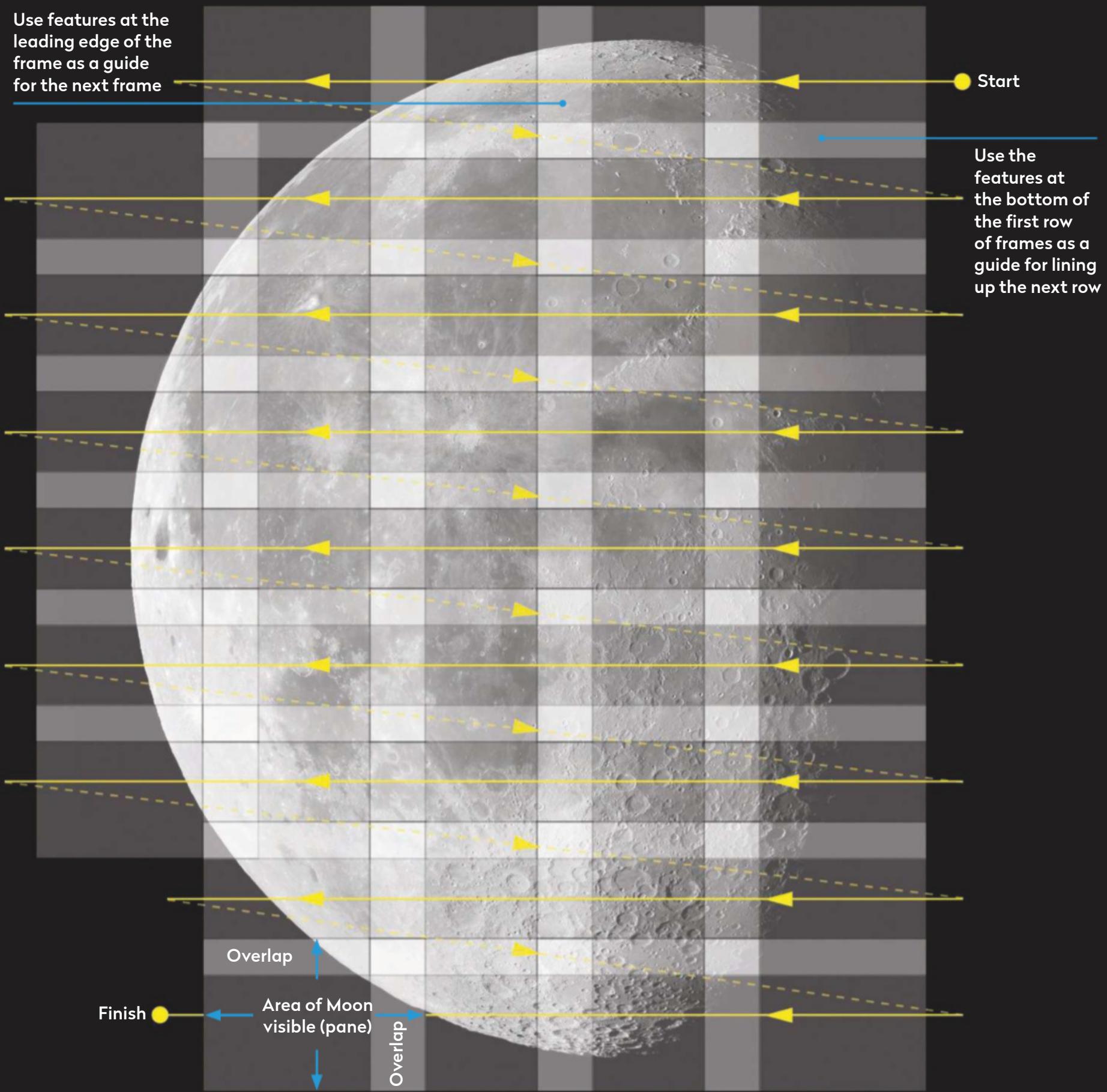


6 Blur and blend

Use the eyedropper to sample the sky colour and use it to fill a layer between the shots. Set the new layer's blend mode to Lighten and merge with the correctly exposed layer. Apply a Gaussian blur to the top layer's mask and apply until the images join.

MASTERCLASS 3

Blend multiple exposures into a lunar mosaic



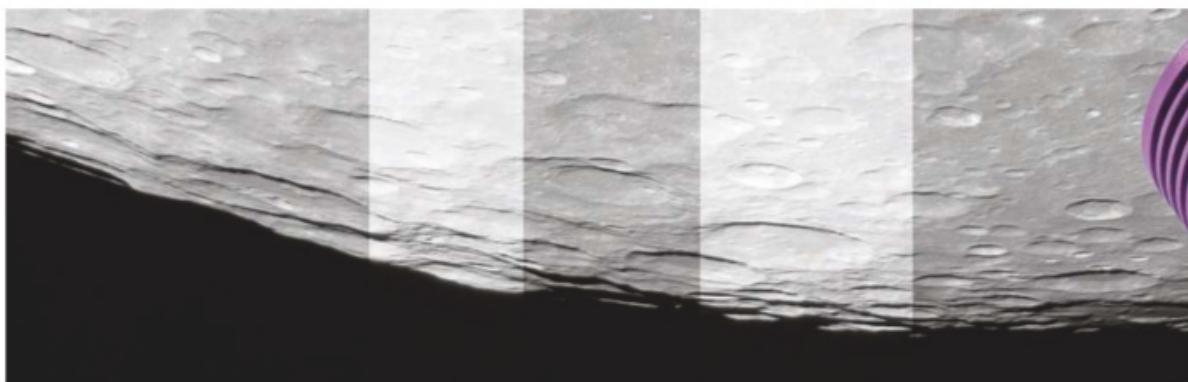
Before you can create a mosaic, you need detailed pictures. A mono, high frame rate camera is the best tool for the job, as it allows you to record a short video of each 'pane' (segment of the lunar surface) as an AVI file, the individual frames of which can be stacked into a still image. If your camera doesn't have an infrared-blocking filter

built in, consider attaching an infrared-pass filter. Doing so can reduce the effects of poor seeing. Alternatively, try a red filter.

Moving across the lunar surface in overlapping panels is something that sounds easy, but there are pitfalls to avoid. The higher the magnification you use, for instance, the easier it is to get

lost and miss a bit out; this is a common frustration when starting out.

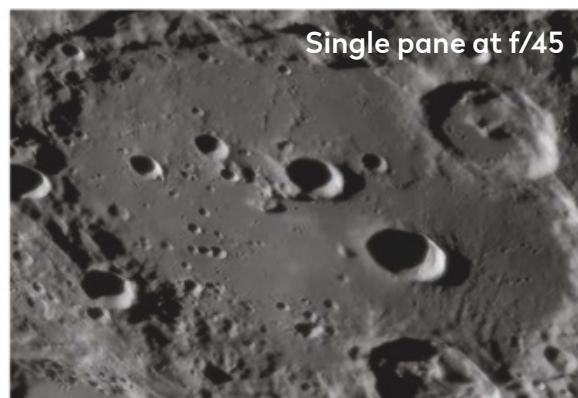
It pays to be realistic in terms of image scale. If you're experimenting with mosaics for the first time, capture a small number of panes to start with so you can get a feel for what's what. Image scale can be adjusted using optical amplifiers such as Barlow lenses, but aim to keep



▲ Lining up your panes with a generous overlap will lessen the chances of missing a piece



▲ At f/15 you'll need fewer panes to complete your mosaic, but at f/45 you'll get more detail



your telescope's overall focal ratio somewhere between f/15 and f/45. Only go higher if the seeing gets really good.

A driven, equatorially mounted scope is ideal. Check your camera's alignment by slewing in right ascension and rotating the camera so that features move parallel to the bottom edge of the frame. Finally, focus your setup.

There are various ways to move across the Moon, but imaging in horizontal strips with lots of overlap is best. A good overlap is typically 20-25 per cent. When lining up your first pane, make a note of features close to the corners of the frame and use these as guides when positioning for the next one.

One direction

It's good practice to image the strips in the same direction, moving back to the same starting side of the Moon between strips. Use features in the first strip of panes to make sure your vertical adjustment has plenty of overlap. A rough sketch of the features in each frame can help. If you lose track, wind back to the last place you know you definitely imaged. It's better to risk duplication than a gap!

Point your telescope at the brightest part of the Moon and adjust your camera's gain and exposure so peak saturation is around 90 per

cent. You should now be able to leave this alone. You can adjust the exposure levels for each frame if you want, but this is more time consuming and requires greater effort when it comes to stitching your panes together; the advantage is less noise in dark regions and extra navigational detail when crossing seemingly featureless areas, such as the lunar seas.

What you'll need to do during a long mosaicing run is refocus often. This is essential to prevent defocusing caused by temperature variations. A 12V camping hairdryer is also invaluable for removing moisture from dewed-up optics during long runs. Two final tips: mosaic captures typically take up lots of



▲ High frame rate cameras are the best choice for lunar mosaicing

computer hard drive space, so make sure you have plenty free; and plan ahead to make sure the Moon doesn't disappear behind by a tree or rooftop part of the way through your imaging session.

Speed up the process

The next step is to process each AVI file to produce one still image, ready for assembly into the final mosaic. For a large mosaic made with many panes this can be a daunting and tedious task, but there are ways to speed things up.

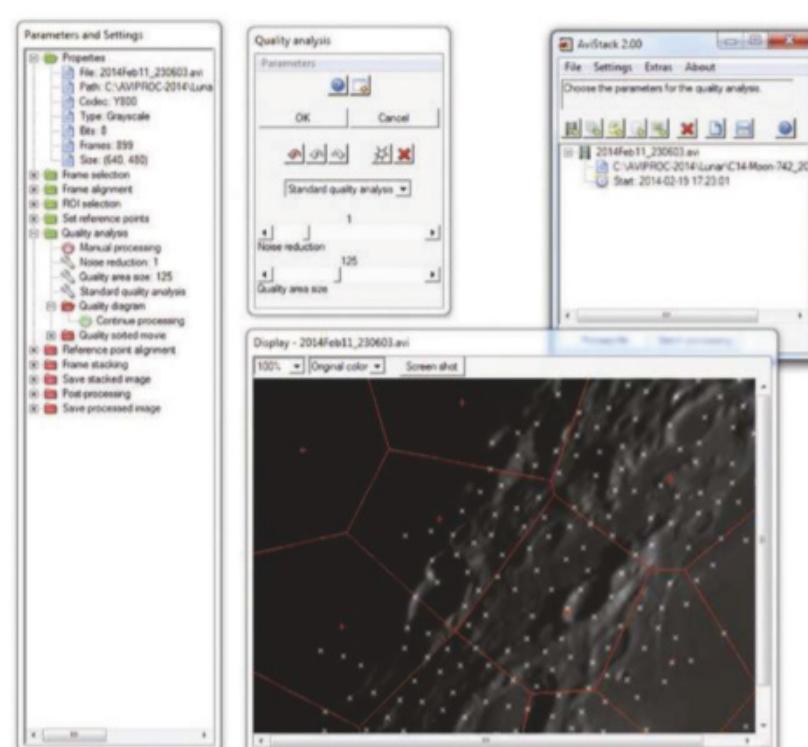
The first step is to analyse, register and stack the frames captured in each AVI file. There are various good free programs that can do this for you, including RegiStax, AutoStakkert and AviStack. We'll be using AviStack for the bulk of the processing and RegiStax to perform wavelet sharpening on the results.

The analysis step determines the quality of each still frame and then ranks them in order of how good they are. A user-set quality threshold then determines how many of the frames

are used. The frames that are above the threshold are 'registered' (aligned) to one another. These are then 'stacked' (averaged) to produce a final image.

The higher the quality threshold, the fewer frames will ultimately go into the stack. This will result in the sharpest output, but with fewer frames to average, noise is more noticeable. Set the quality threshold lower and there will be more frames to average, resulting in a smoother, less noisy result. But using lower-quality frames reduces overall image sharpness.

It's a good idea to perform a number of test runs using ▶



▲ Quality analysis determines which frames will give you the best results. Higher quality potentially means more noise

► AviStack if you're not familiar with the program. There are a lot of settings that can be configured; these are shown in a separate window and can be viewed by expanding the tree list. Double clicking on a parameter section, for example 'Frame selection', will bring up a control window allowing you to adjust the settings. You can toggle between automatic and manual processing by clicking on the gear icon below the section header. Setting the toggle to 'Automatic processing' lets AviStack make decisions for you, which can be useful if you're not sure what you're doing.

AviStack has a great batch-processing mode that can work on large numbers of AVI files unattended. The end result is a single distilled image for each AVI capture. Various output formats are available, but we recommend PNG as this is a lossless format that many editing programs and file viewers can easily display. Other lossless files can be used, but how easy they are to view and manipulate varies. Avoid formats such as JPEG that use 'lossy' compression – these discard data to make files smaller.

Following the step-by-step guide below, the initial process delivers results

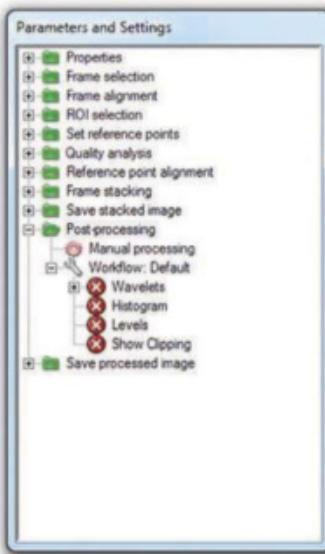
with no sharpening. To the eye these will look blurred, so to address this we'll apply the excellent wavelet sharpening function in RegiStax.

Sharpening lunar images needs to be done with great care – it's easy to get carried away and push it too far. If in doubt, leave the image up on your computer screen and walk away from it for a while. When you come back, your initial reaction will be a good indicator as to whether you've taken things too far. If you're creating your mosaic at low magnification, a gentle tweak on the first slider is all that's normally required.

STEP BY STEP: Processing your panes using AviStack

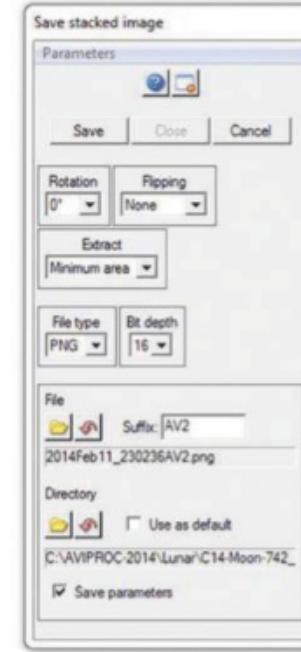
1 Load

Load a single AVI into AviStack. If you're processing it manually, select Settings > Processing > All Manual from the menu. If not, click on All Automatic. Expand the Save Stacked Image section and check Manual processing is set; click on Automatic processing if shown. Expand the Post processing section and select Manual processing. The four options below should be deselected.



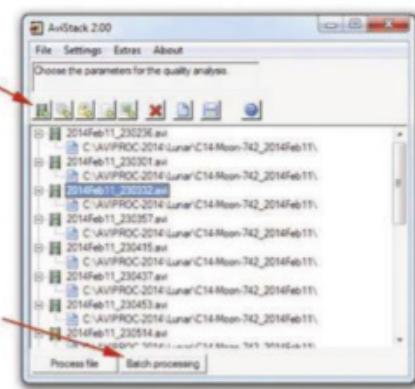
2 Save

Click on Process File. In the Save stacked image window (right) select PNG as the file type and pick a folder to save it to. Make sure Save Parameters is ticked before you save. Hit Cancel when the Post processing window appears. Check if the result needs wavelet sharpening (see step 5). If not, repeat and adjust parameter settings in a manual run using the help options to assist.



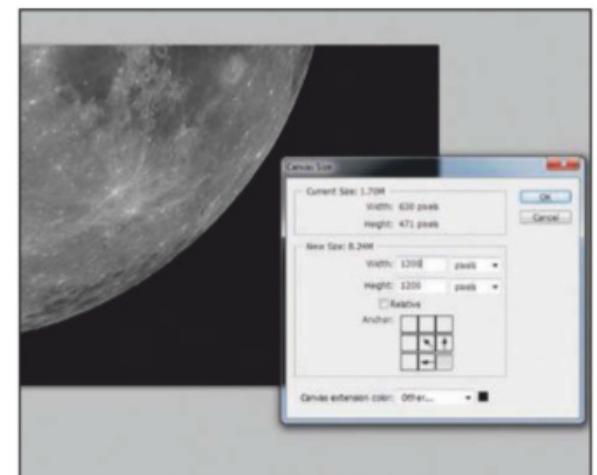
Add Movies (file open)

Batch processing



3 Batch Process

That's your first processed file complete. The settings for this file will be used for the batch processing run. Click Add Movies and select all of the files to be processed, then click Open. Finally, click Batch processing and let the program run through each file, saving the results as per the settings you chose in the save stacked image box in the previous step.

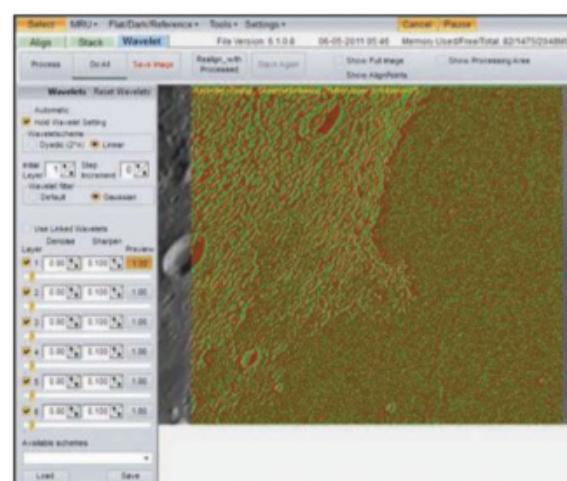


4 Keep the originals?

Once you have all the AviStack-processed PNG results, copy them to a new folder called 'Wavelet-sharpened'. These are the files you'll edit in RegiStax, but leaving the originals untouched means you can rework them if new techniques become available. Once you have your final results, the originals can be discarded if you need the disk space.

5 Sharpen

Run RegiStax and click Select. Change Files of Type to match the format of the processed images (in this example, PNG). Load the first image. With the Wavelet tab selected, click on the preview buttons to see which details will change. Use the slider that shows the finest detail that isn't just noise grain. Adjust the sliders to sharpen the image to taste.

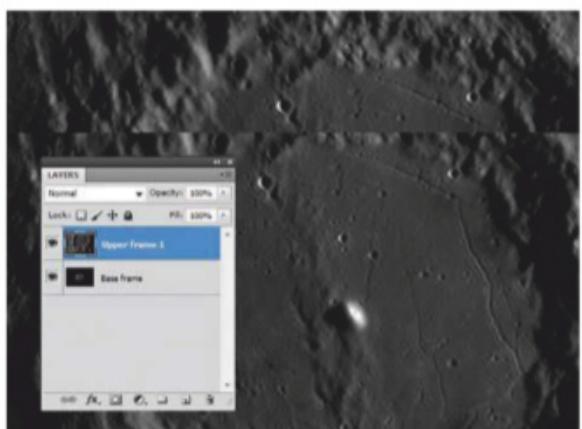


6 Begin the mosaic

Wavelet sharpen all of the images, saving each when done. Next, load the first image into a program such as Photoshop or GIMP and crop any unwanted edge artefacts. Estimate how big the canvas needs to be to hold all the panes and resize it. Don't worry if you get it wrong as you can adjust it later. Select a black background for the new canvas.



Whether a full disc or a partial phase, a lunar mosaic is one of the most rewarding images you can produce



▲ Align your panes by zooming in and nudging them into place with the arrow keys



▲ You may need to adjust brightness and contrast to blend adjacent panes together

The most exciting part of mosaicing is building the final image. There are free programs that can do this automatically, such as Microsoft's Image Composite Editor (ICE). Building the mosaic manually is more time-consuming, but ultimately a more rewarding experience. Doing it yourself can also help to avoid the errors that can creep in when you let automated programs carry out the process.

Manual mosaic assembly

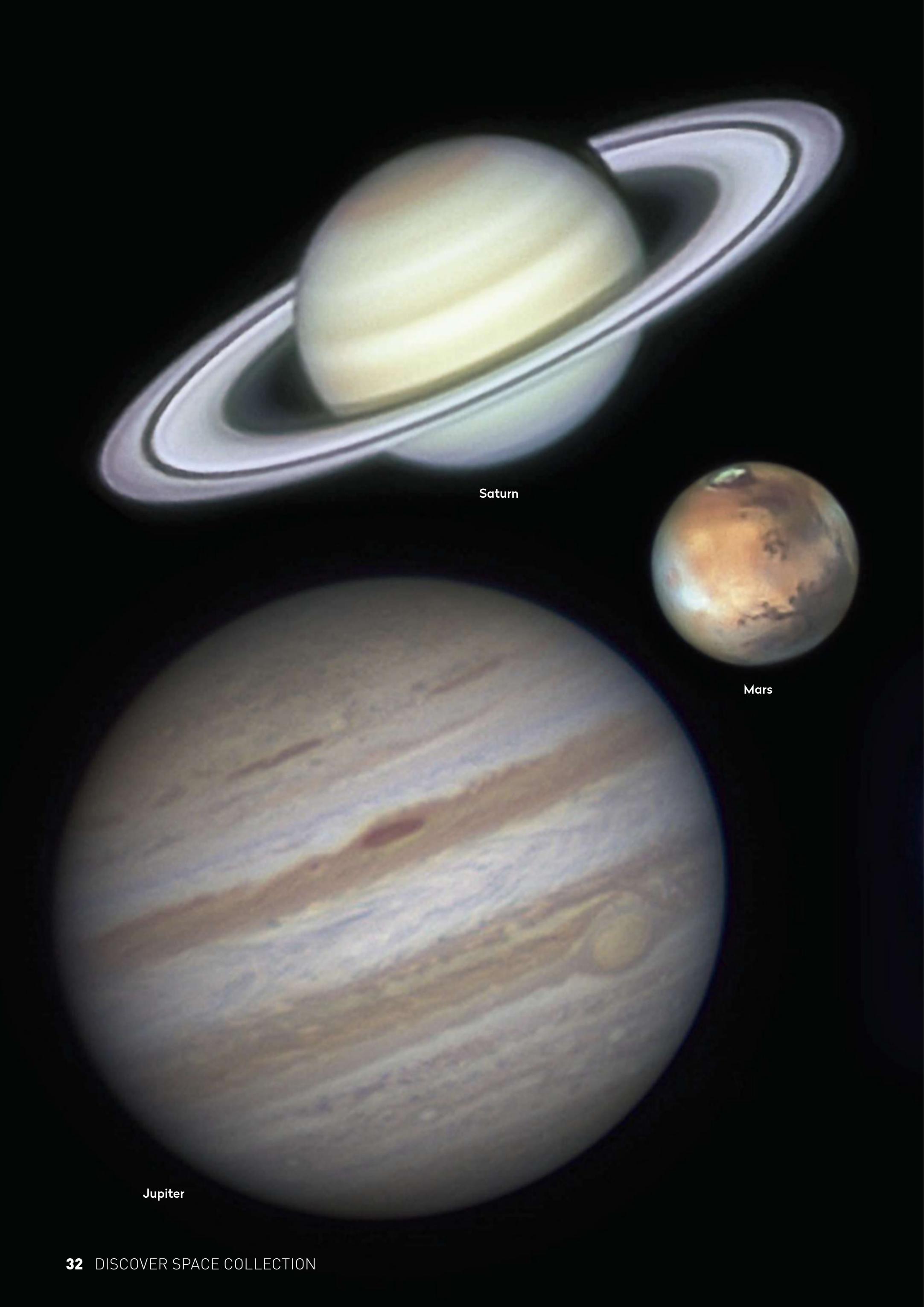
If you followed our step-by-step guide on the previous page, your base image will contain a single, finished pane and your canvas will be big enough to take the rest. Load the next frame in the sequence and draw a selection box slightly smaller than the frame edge.

Apply a 5-10 pixel feather to the selection. Copy the selection and paste it into the base image. Use the arrow keys to align the pane with the lower image. Toggling the visibility of the pane on and off will help you align it accurately.

Small variations in tone between the pasted and base images can normally be dealt with by gently tweaking the curves tool – you should apply the adjustment to the centre of the curve. For larger variations, raise or drop the brightness of the image first to get it closer to where you want it, then use the curves tool to carry out fine adjustments. The feathered edges of the pasted image pane should make any straight edges hard to see. If some are still obvious, set the eraser tool to 10 per cent and gently rub it over any visible joins; this should hide them.

For very large mosaics that stretch your computer's memory, assemble a batch of panes and then save the layered image to a file called 'mosaic-001'. Flatten the image and continue loading with the next set of frames. When you get to a similar stage as before, save as 'mosaic-002' and flatten. Repeat until the whole mosaic is complete. Doing this means you can go back and address any major problems.

When you're finished, flatten the image and save it with a file name of your choice. A gentle tweak of brightness or contrast, or a small adjustment using the levels and curves tools, can help to finish off your masterpiece. It takes a bit of work to build such a mosaic manually but once it's done, the feeling of satisfaction will be immense... Unless you've missed a bit of course!



Jupiter

Saturn

Mars



◀ The planets. Each of these images were taken by amateur astronomers with Earth-based telescopes no larger than 14 inches in aperture

Neptune

Uranus

Mercury

Venus

THE PLANETS

Photographing the planets can, even in today's enlightened times, lead to surprising discoveries. Often the announcement of an impact on Jupiter or storm on Saturn comes from an amateur, having been recorded by a planetary imager. In this section we'll consider all of the planets, from Mercury out to Neptune. Some of these worlds,

such as Mars and Jupiter, appear more dynamic than others, so we'll concentrate on these to illustrate some of the techniques needed to image the planets. The best time to image a superior planet (one that has an orbit larger than Earth's) is around opposition, so we've supplied a table to give you prior warning of the next time this is due to occur. ▶

WHAT YOU'LL LEARN

34 Equipment

Everything you'll need to take sharp, colourful images of our neighbours in the Solar System

36 Technique

Get prepared for nights of planetary imaging with our how-to guide for beginners

38 Masterclass 1

Capture striking images of the many beautiful features on Mars with a colour camera

40 Masterclass 2

Use a mono camera to capture a colour image of Jupiter with our guide to filters and stacking



Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

OUR EXPERT

EQUIPMENT

All the gear you need to photograph the planets

The planets are on our cosmic doorstep, yet you still need a telescope with quite a bit of magnification to see any of their surface details. To see more detail, you need to increase the magnification or image scale (how big an object appears in the image frame). This is determined by the focal length of your telescope. As a telescope's focal length is fixed, you might think that it can only give one magnification, but this isn't the case – optical amplifiers such as Barlow and Powermate lenses can effectively increase it, while focal reducers effectively lessen it.

Focal ratio (f-ratio) gives an indication of the 'speed' of an optical system – the time it takes your telescope to deliver a set amount of light. As the f-ratio goes up, so the image scale increases: the object appears larger and consequently dimmer. The f-ratio is defined by dividing your telescope's focal length by its aperture using the same units. So if you have a 100mm refractor with a focal length of 900mm, its f-ratio is said to be f/9. Adding a 2x Barlow increases the

► Large Schmidt-Cassegrains are a popular choice for capturing the planets

▼ A large aperture apochromatic refractor would make an ideal planetary imaging scope

effective focal length to 1,800mm and doubles the f-ratio to f/18, but there is a limit to how much focal length is useful.

Large values make the image appear dim and require lower frame rates and longer exposures, and beyond a certain value, your telescope won't be able to



TECH TALK: Why use filters?

Filters are frequently used in planetary imaging to enhance certain wavelengths, or to prevent some of them from getting to the camera. Imaging chips are often very sensitive to infrared light; unless checked, this can oversaturate and wash out detail. An inexpensive infrared-blocking filter can prevent this.

Mono cameras can take full-colour images using red, green and blue (RGB) imaging filters placed one at a time in front of the camera's sensor. Some of



▲ Filters produce a range of effects: some add colour while others block certain wavelengths

these cameras have an infrared-blocking filter fitted as standard. Other types of filter commonly used are infrared-pass filters such as the popular 742nm 'planetary filter'. This lets through longer wavelengths of light, which can often appear less prone to atmospheric turbulence, and produces a sharper image. Specialist filters such as methane-band (CH4) or

ultraviolet-pass are also sometimes employed to pick out planetary details that would otherwise be hidden.

deliver any more useful detail. Under average seeing conditions, figures of f/15-f/25 will probably work best. If you are lucky enough to experience excellent seeing, values in the f/25-f/45 range can be effective.

Balancing act

A range of optical amplifiers of different magnifications will help you achieve the right value for your setup, but a key skill in planetary imaging is knowing how to select the best image scale for the prevailing conditions.

Apertures of 8 inches or larger are best for high-resolution planetary imaging, and the ideal telescope would be a large aperture, long focal length,

"If you have a smaller telescope, don't worry: telescopes under 8 inches in aperture are also capable of capturing some detailed shots under the right conditions"

colour-corrected (apoachromatic) refractor. This kind of scope is great for providing the unobstructed, high-contrast views necessary to reveal detail on a planet's disc. Reflecting telescopes can also be excellent planetary scopes, but to get high image scales you need a long focal length instrument. As aperture increases, such an instrument can become heavy and cumbersome, making it difficult to mount and handle.

One popular design for planetary imaging is the catadioptric scope, which uses both mirrors and lenses. The Schmidt-Cassegrain design balances size and performance with affordable cost. And since the optics of this kind of scope effectively 'fold' the light path, a large aperture, long focal length Schmidt-Cassegrain is also fairly easy to handle. You'll also need a solid mount for planetary imaging. Ideally an equatorial

design, polar aligned with driven right ascension and declination axes.

If you have a smaller telescope, don't worry: telescopes under 8 inches in aperture are capable of capturing some detailed shots under the right conditions. The key is to keep the image scale realistic for the size of the scope and conditions. A family portrait of Jupiter with its four Galilean moons, for example, can be just as stunning as a close-up.

CAMERA CHOICE

Smartphone



Smartphone cameras have advanced to the point where they can take basic shots of planets afocally, through the eyepiece of a telescope. There are also accessories available to attach them to the telescope's eyepiece.

Planetary



The first step on the multi-frame imaging ladder is a medium frame rate camera such as the Celestron NexImage. Pre-fitted with a 1.25-inch eyepiece adaptor, they often come bundled with good software.

High frame rate



Top of the pile are dedicated high frame rate cameras, like those from ZWO, PGR and Lumenera. With high-speed connections such as USB 3.0, rates of several hundred frames per second are common.

PRO POINTER: Seeing and planetary imaging



Light from a planet must pass through our atmosphere before it reaches us and as it does pockets of air at different temperatures and densities bend or refract it. This blurs the details that we can see. The state of the atmosphere and its effect on the appearance of celestial objects is known as 'seeing'. Excellent seeing is something of a rarity in the UK; when it does occur, it's really something to behold, but for the most part we have to make do with average seeing.

An eyepiece view of a planet under average seeing conditions often gives fleeting views where everything looks sharp. You can appreciate these brief moments when you're looking through a telescope, but snap a planet with a DSLR camera under average seeing conditions and it'll look distorted and blurred.

DSLRs are commonly used to take stunning long-exposure astrophotos of deep-sky objects but, in the past, were rarely used for the planets due to Earth's turbulent atmosphere. A single exposure of a planet will, unless you're lucky, record slightly blurred detail, smeared out by the



▲ A single shot of Jupiter (top) shows far less detail than you can get by stacking frames extracted from a video (above)

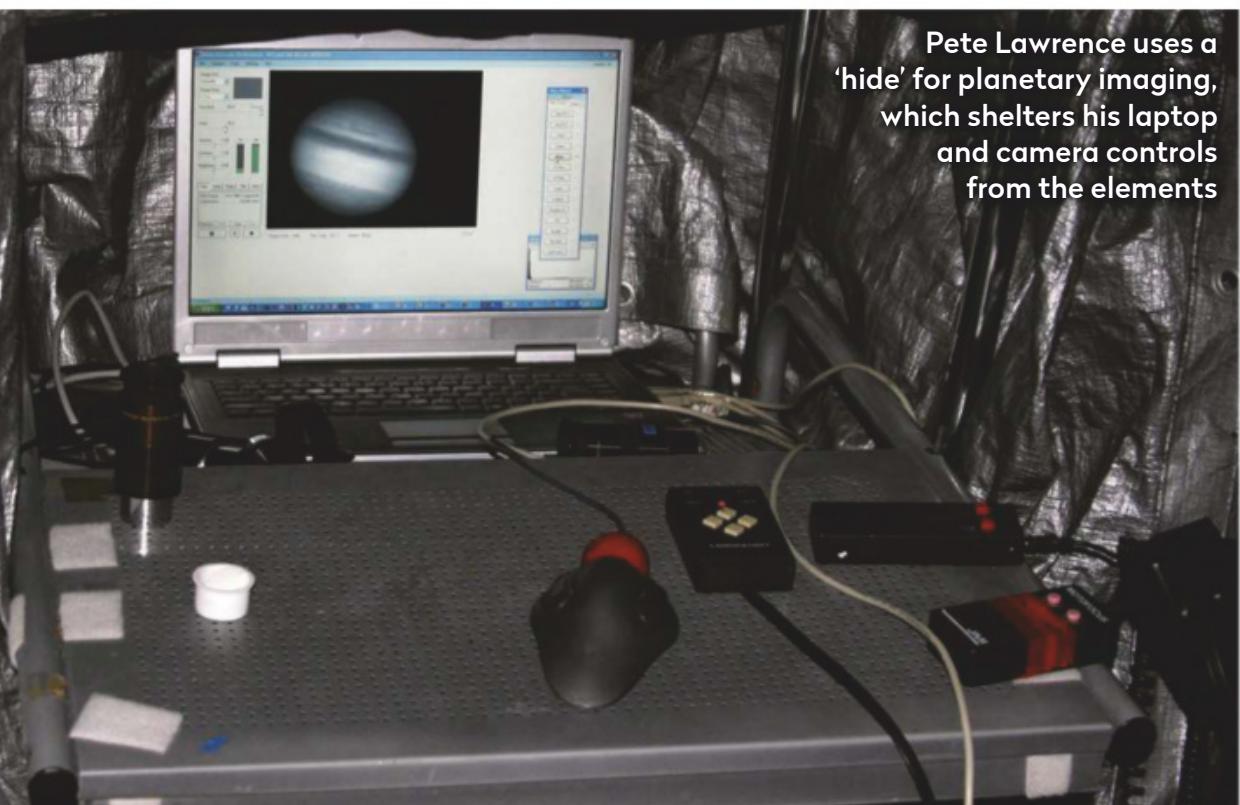
atmosphere. One way around this is to record a video of the planet. This way you'll capture lots of poor-quality images, but there should be a few good frames among them. Using specialist software, you can extract these frames and combine them to make a sharp image.

Devices that can do this range from webcams, the latest DSLRs, which can now take video, through to purpose-built planetary cameras with high frame rates, specifically designed for this task. As rapid frame rates require short exposures, a high-sensitivity, low-noise imaging chip is also needed and this is why monochrome cameras are preferred. Despite colour cameras being more convenient for one-shot colour imaging, the fixed Bayer matrix filter they use to create the colour doesn't permit as high a sensitivity or control as an equivalent unfiltered mono camera.

Unlike a DSLR, a high frame rate camera has no controls of its own. A separate computer with an appropriate driver and control software is required to issue commands to the camera.

TECHNIQUE

Master these methods to capture the planets



Pete Lawrence uses a 'hide' for planetary imaging, which shelters his laptop and camera controls from the elements

Planetary imaging is easy if you know what you're doing. But it's important to remember that many of the amazing amateur images you see on the pages of *BBC Sky at Night Magazine* have years of practice and experience behind them. Don't let that

put you off, though, because gaining that experience can be a lot of fun.

For basic planetary imaging you should be using a polar-aligned, equatorially mounted telescope fitted with right ascension (RA) and declination (dec.) drives for ease of repositioning. You'll need

to place it outside for two to four hours before you start imaging so the instrument can cool down to match its surroundings. This should be timed so that you can start imaging when your target is close to due south and highest in the sky. Also, your telescope's optics must be properly collimated (its instruction manual will explain how to do this).

Start by aligning the finderscope to the eyepiece view. Your scope's RA drive should be on at this stage and, once the planet is centred in the eyepiece, swap in the camera. Use the control software to select a low or medium frame rate. Increase the gain (the signal amplification) and exposure until the background is slightly brighter than black. Don't worry about focus, you're just looking for a sign of the planet. Gentle pressure to the scope's tube should reveal it if it's just outside the frame edge.

Once you've found your planet, centre it and re-align the finderscope for future sessions. It's a good idea to rotate the camera so that the planet moves parallel to the bottom of the frame when the

PRO POINTER: How to prepare for a night of planetary imaging



Cool your kit

Minimise the risk of air currents inside your telescope affecting image quality by letting it cool down outside before you start imaging. Scopes up to 8 inches in diameter need about two hours to cool; give larger instruments three or four hours. Time the cooling to end when your target planet is close to its highest point.



Check collimation

All of your scope's optical components need to be collimated (perfectly aligned) to get the best results. This is especially important with fast scopes that have focal ratios of f/5 or lower, as these are significantly less tolerant of collimation errors. Refer to your scope's instructions to find out how to check and collimate it properly.



Upgrade the focuser

High-resolution imaging requires precision focusing. Long focal lengths will magnify any issues with a focuser, such as image shift and wobbles caused by you touching the focuser knobs. One solution is to use an in-line electric focuser, which lets you adjust focus remotely and keeps the camera in the same position when it's in use.



Add a filter wheel

Mono high frame rate cameras are best for imaging planets. They can be used to create full-colour RGB images with the help of filters. Fast-rotating planets need quick changes of filters to avoid motion blur on the captures. A filter wheel makes swapping filters easy and electronic versions remove the need for any physical contact.

TECH TALK:

Keeping your target in the frame

It is possible to do planetary imaging on a static tripod head with no drive but, frankly, it's really hard work. Ideally, your telescope needs to be on a sturdy, polar-aligned equatorial mount. Although accurate alignment is desirable, simply pointing the mount's polar axis at the north celestial pole using a basic polarscope is normally sufficient to achieve the accuracy needed.

Motor drives on the RA and dec. axes are also desirable. These can be used to make corrections if the planet drifts, even when you're in the middle of a live capture run. A slow positional adjustment rate – 2x sidereal speed or less – will normally give you enough fine movement control to compensate for any shifting of the planet within the frame of the imaging chip.



► A motorised mount is highly desirable for planetary work

There is a school of thought that says a bit of movement of the target on the imaging chip is no bad thing. It allows the registration and stacking program you'll be using after the capture to even out some of the optical irregularities in the image frame, such as dark spots caused by dust on the chip.

scope is moved in RA. Make a note of this orientation relative to the mount so you can use it next time.

Next you need to focus and get the camera settings right. Focus as best you can before adjusting the camera's frame rate, exposure and gain. Contrast, brightness and, if your camera has it, gamma should be left at their default, unadjusted levels.

The ideal setting would be one with a high frame rate, low gain and short

exposure (which also helps the frame rate). Control software, such as FireCapture, will typically offer a range of exposure speeds. Select the fastest range first, then adjust the exposure and gain so that the signal strength is about 85–95 per cent saturated. If the gain needs to be almost maxed out to achieve this, select a slower exposure range, and re-adjust the gain and exposure settings to suit. Keep the maximum saturation the same for each filter.

To focus, carefully wind the focuser through the point of focus and out the other side several times. When you're confident you know what the point of focus looks like, wind to that position.

Make a movie

Now you're ready to capture a movie sequence. Common formats to save the file in are AVI, SER, Raw or as a sequence of stills. We'd recommend saving as either AVI or SER. AVI is limited to 8-bit frames (256 tones) while SER can be deeper. The more bits used, the greater the amount of data that must be transferred.

Aim to keep your captures below the time limits listed in the table below. Frame counts of 2,000–3,000 per file are ideal, but you may find slower cameras will struggle to achieve this. Remember, the values listed in the table are 'per channel' (red, green and blue), so with a colour camera you can get away with three times the limit for an individual channel.

Some programs automatically name the files, while others require you to do it manually. If you name them manually, adopt a standard naming convention for your capture files such as 'yyyy-mm-dd hh-mm-ss_filter.avi'. Capture files can be large, so we recommend you have at least 50–100 GB of free space on your hard drive per session.

When capture has been completed, the next step is processing. Use a registration and stacking program such as RegiStax or AutoStakkert to pick out the good frames from your capture files and stack them to produce a polished end result.

ELONGATIONS & OPPOSITIONS: Key dates for the future

Planet	Capture limit (<10m focal length)	Capture limit (>10m focal length)	Next observing highlights
Mercury	Not critical	Not critical	Elongations: 23 Jun 2019 (eve), 9 Aug 2019 (morn), 20 Oct 2019 (eve), 28 Nov 2019 (morn), 10 Feb 2020 (eve), 24 Mar 2020 (morn)
Venus	Not critical	Not critical	Elongations: 24 Mar 2020 (eve), 13 Aug 2020 (morn), 29 Oct 2021 (eve), 20 Mar 2022 (morn)
Mars	2-3min per channel	1-2min per channel	Oppositions: 13 Oct 2020, 8 Dec 2022, 16 Jan 2025, 19 Feb 2027
Jupiter	1min per channel	30-40sec per channel	Oppositions: 10 Jun 2019, 14 Jul 2020, 19 Aug 2021, 26 Sep 2022
Saturn	1-2min per channel	1min per channel	Oppositions: 9 Jul 2019, 20 Jul 2020, 2 Aug 2021, 14 Aug 2022
Uranus	Not critical	Not critical	Oppositions: 28 Oct 2019, 31 Oct 2020, 5 Nov 2021, 9 Nov 2022
Neptune	Not critical	Not critical	Oppositions: 10 Sep 2019, 11 Sep 2020, 14 Sep 2021, 16 Nov 2022

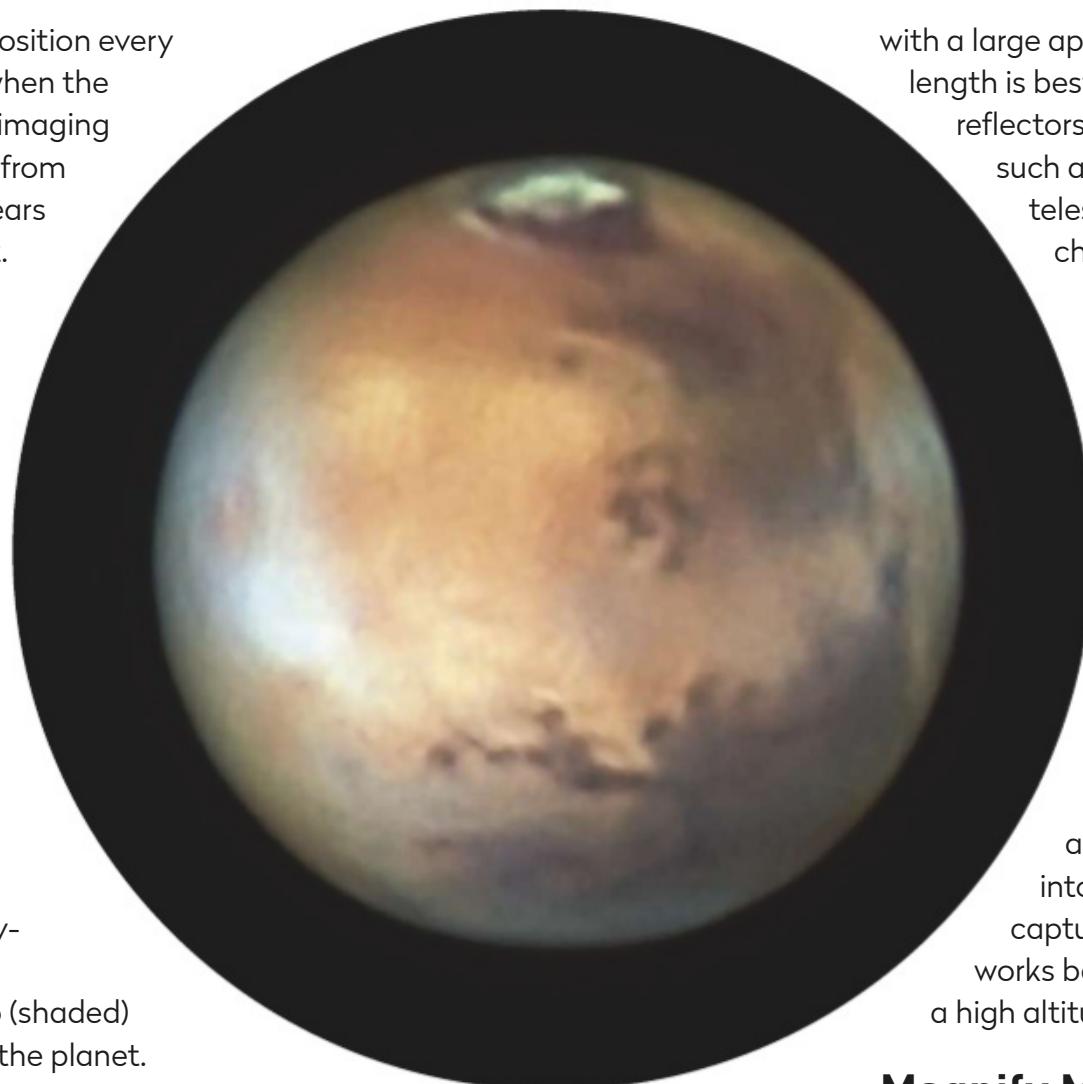
MASTERCLASS 1

Capturing Mars with a colour camera

Mars comes to opposition every 2.1 years. This is when the planet is best for imaging since it's opposite the Sun from our point of view and appears at its largest and brightest. The next oppositions occur in October 2020, December 2022, January 2025. From the UK, the planet's position will become optimal in terms of altitude and apparent disc size in 2020 but thereafter the disc size will begin to shrink with each successive opposition.

Through a telescope there's plenty to observe both on and above the Martian surface. The reddish-brown deserts of Mars are interrupted by dark albedo (shaded) markings that rotate with the planet.

Mars has seasons and the effects of these can be seen in the growing and shrinking of the planet's polar ice caps. There's weather too, of course, and the appearance of bright clouds or dust storms all add to the excitement of imaging this fascinating world. High surface features, such as giant volcanoes, affect the Martian atmosphere. Here you may find bright 'orographic' clouds forming, as the atmosphere is forced up above the volcanoes.



▲ An image of Mars can reveal dark, 'albedo' regions and the presence of a white polar cap

It takes slightly more than an Earth day for Mars to rotate – 24.6 hours – which means that the planet looks very similar from one night to the next, changing more noticeably over the course of several weeks. Detail is subtle and finely structured, so a high-contrast telescope

with a large aperture and a long focal length is best for imaging. Large reflectors or catadioptric scopes such as Schmidt-Cassegrain telescopes are a popular choice for imaging Mars.

Although a high frame rate camera with filters will produce the best images of Mars, a colour planetary camera helps to keep the capture time to a minimum, which is useful since the planet rotates relatively quickly. There's also less equipment to set up and you won't need to spend as long processing colour into the image after you've captured it. A colour camera works best when Mars reaches a high altitude.

Magnify Mars

The planet holds up well even under average seeing conditions, so don't be afraid to pile on the magnification by using an optical amplifier such as a Barlow lens. Aim to keep your scope's focal ratio in the region of f/25 to f/45. By following the methods explained in the technique section on the previous page, you should end up with an image of the planet that shows a bright and tangible disc.

THE OTHER INNER PLANETS

Mercury



The innermost planet is tricky to image because it never strays far from the Sun. This makes it hard and quite dangerous to locate when the Sun is above the horizon. It also keeps the planet's visibility limited to either before sunrise or after sunset. The best time to image Mercury is when it's close to maximum elongation, in the evening sky during the spring months or in the morning sky during the autumn months.

Venus



Venus shows little detail even in high-resolution images. It has the advantage of being bright and easy to locate, and it strays further from the Sun than Mercury. The planet shows phases like Mercury, but its apparent size can get much larger. Specialist filters that pass just ultraviolet light,

such as the Schüler UV type of filter, can be used to enhance some of the subtle cloud features on the planet.

STEP BY STEP: Refine your image with RegiStax



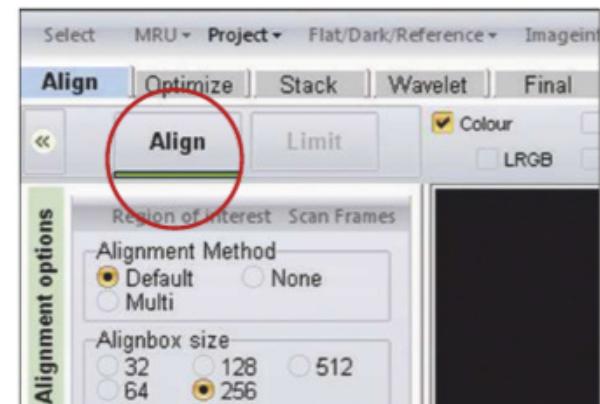
1 Select a reference frame

RegiStax analyses your capture file to assess how sharp each frame is. Load your capture file (typically in AVI format) using the Select option, then adjust the lower slider so that a really sharp frame is displayed. This will be the reference against which the others are compared.



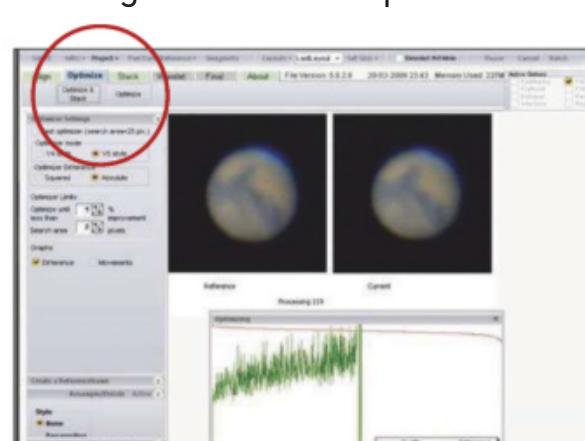
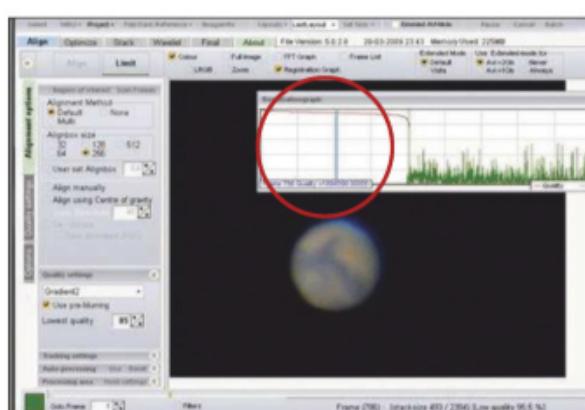
2 Place the alignment box

Place an alignment box over an area of high contrast in the reference frame. Typically this will be the main planet's disc, so choose an appropriate size but don't worry if some of the disc falls outside the box. Move the cursor over the image and left click to place the box.



3 Align

Check the Use Pre-Blurring option and then click on the Align button. RegiStax runs through each frame, comparing it to the reference frame. The end result is a 'RegiStrationgraph'. A red line shows the image quality and a green one shows the movement shift between frames.



4 Adjust quality threshold

There's a quality bar in the RegiStrationgraph, which can be moved using the bottom slider of the main window. Sliding right adds more frames and improves noise, but brings more poor quality images into play. Adjust it until the red line indicates 80-90 per cent quality.



5 Limit and process

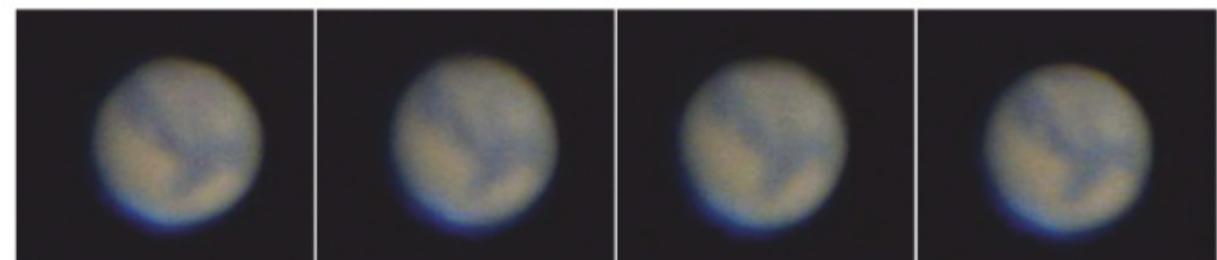
With your decision on the placement of the quality bar made, click Limit. This tells RegiStax to ignore any frames to the right of the bar. Next click on Optimize & Stack, which instructs RegiStax to align all of the images and then combine them in a stack to reduce noise.

6 Process wavelets

The Wavelets control sliders allow you to sharpen different details in the processed image. Click on each slider's preview button to reveal the detail that will be affected by the slider. Choose the level that you find works on detail rather than noise, and move the slider to the right.

If your camera has a gamma control option, keep it set at the default level, adjusting exposure and gain to get the level right. An infrared-blocking filter is essential for good results and some colour cameras have them built in. If yours doesn't, you can buy one for around £30 that will screw on to your camera.

It can be tricky to get the right colour balance with Mars. If you've managed to get a large and bright planetary disc in the frame, try using the camera's auto colour-balance function before manually adjusting your camera's colour settings. If necessary, push the gain up high to get a bright enough signal. This should also alleviate the so-called 'onion-ring' effect, which can occur after registration and stacking has been applied. Under certain



▲ Four frames from an AVI file reveal Mars. Stacking these together will bring out fine detail

seeing conditions you may get a 'false edge' effect on processed results; however, you're at the mercy of the sky.

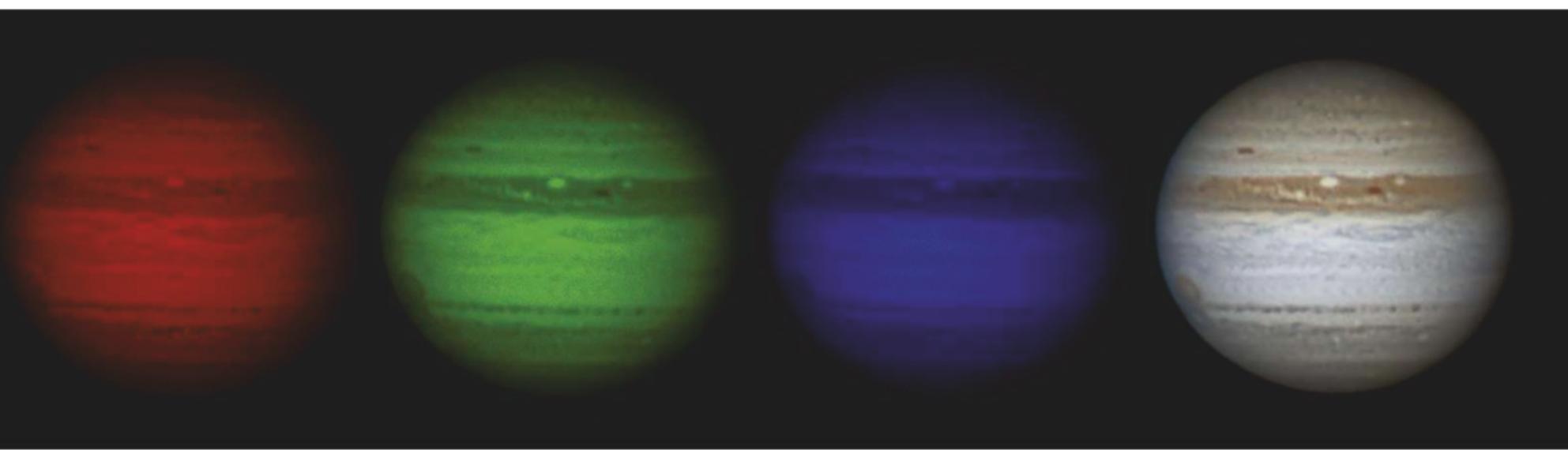
The capture file will need to be processed with registration and stacking software such as AutoStakkert or RegiStax. These pick out the best frames, align them, then stack them together automatically to reduce noise. For this to work well, you need a good number of frames to start with, and high frame rate

cameras can easily generate several thousand frames during a capture run.

When passing the capture file through stacking software, expect the number of frames in the final stacked image to be just 10-20 per cent of the total. If you can see colour fringing, this can be corrected by realigning the colour channels – either in a graphics editing program or using the RGB colour-align function some programs have.

MASTERCLASS 2

Create a colour image of Jupiter with a mono camera



▲ Combining red, green and blue images of Jupiter will create a full-colour shot with a high level of detail

Jupiter is one of the best planets to image because it's big, bright and has a dynamic atmosphere full of rapidly changing detail. The planet rotates quickly – features take slightly less than 10 hours to go all the way around. Consequently, if you take too long to image Jupiter you may find its detail is smeared out and lost due to motion blur.

Jupiter is an ideal target for all types of telescope. Even a small one will be able to capture the planet's disc, main belts and the Great Red Spot. If you do have a small telescope, Jupiter is a great object to consider for a 'family portrait,' featuring the planet and the four Galilean moons. As telescope aperture increases, so does resolving power, and large telescopes will be able to resolve

increasingly finer detail, as long as the seeing cooperates.

Synthetic colouring

Imaging Jupiter with a monochrome camera and colour filters presents some interesting timing issues. You don't have long to complete each colour channel (see 'Elongations and oppositions' on p37), which is where a filter wheel really comes into its own. If you're struggling to get all three RGB channels done in time, creating the green channel synthetically (a technique we explain on page 92) will help you to reduce capture times. Whichever method you use, it's important to remember to re-focus between filter changes.

Earth's atmosphere disperses shorter wavelengths more than longer ones,

meaning that your red-filtered images will appear sharper than the blue ones. Similarly, an infrared-pass filter, such as the popular Astronomik IR Pro 742nm, can produce an even more sharply defined result at the long-wavelength end of the spectrum. This is countered somewhat by the fact that image brightness with an infrared filter is much lower than with a normal red filter.

Although it will distort colour and over-emphasise features to a certain degree, an infrared-pass result can be substituted for the normal R component, giving rise to an IRGB image. Similarly, the original R or IR channel can be used as a luminance layer to give an RGBR or IR-RGB result. Again, these techniques produce images that don't necessarily reflect the real colours or contrast values

THE OTHER OUTER PLANETS

Saturn



Saturn's beautiful rings are a big attraction. Surface detail can be subtle with gentle banding and the occasional white spot representing a storm in the planet's atmosphere.

Saturn is dimmer than Jupiter so exposures typically need to be longer, resulting in reduced frame rates. An 8-inch or larger scope is recommended for detail, aim for f/15-f/25. Keep an eye on the planet's position and on the seeing, then take advantage when the atmosphere appears stable!

Uranus and Neptune



Uranus and Neptune are both large worlds, but their distance makes them appear small and dim. To get a decent image scale you'll need to

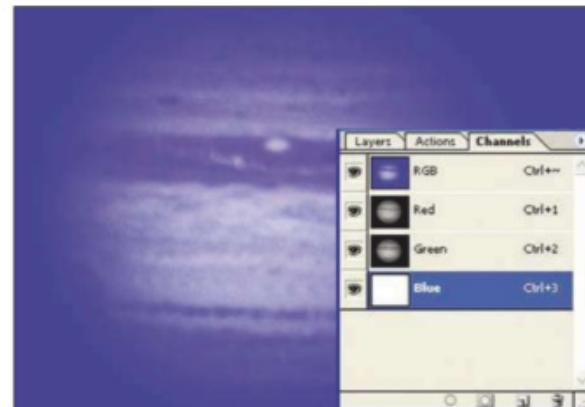
use a long focal length, which reduces the image brightness of both planets. Even so, it is possible to capture them using a high frame rate camera so long as you have a 10-inch or larger scope. You'll need to use a low frame rate and ramp up the gain and exposure times. Capture time limits aren't really an issue here, so you can get a good collection of frames.

STEP BY STEP: Merge your R, G and B images into a full-colour shot



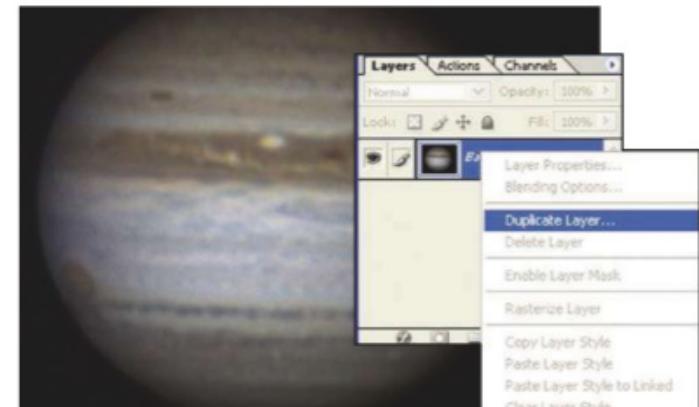
1 Align RGB images

Having processed each RGB channel in RegiStax (see page 39), load the images into a layer-based graphics program. Cut and paste the G and B images into the R image as separate layers. Align the G and B layers with the R layer. Crop the image so that there are no gaps at the edge.



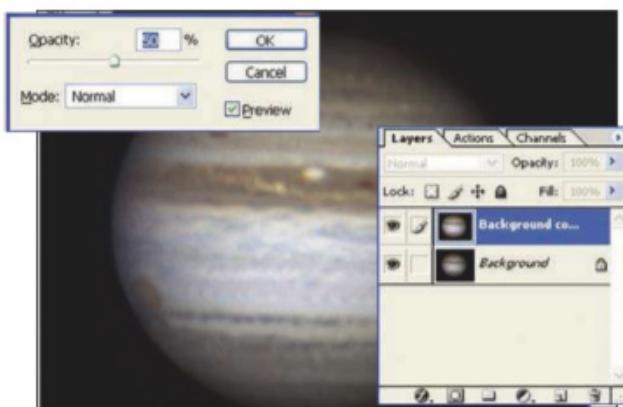
2 Create a blank canvas

Create a blank RGB image with the same dimensions as the cropped image from Step 1. Select this image's blank R channel. Copy the R layer from the Step 1 image into this channel. Repeat with the G and B images, pasting them into the blank image's G and B channels.



3 Turn on the colour

Turn on the visibility of all the channels in the new image and you should have the rudiments of a true colour image. Switch back to the layers view and duplicate the base layer – this will be a safety copy that can be called upon if things go wrong and you need to start over.



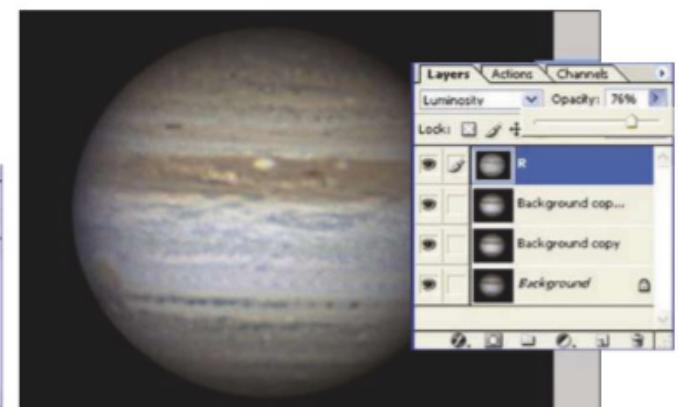
4 Adjust the colour

If the colours look odd, use the software's auto-colour function; if the result looks garish, try reducing the intensity of the process. Manual adjustments can be made with the Colour balance function or by adjusting the colour channels via the Levels or Curves functions.



5 Reduce noise and sharpen

A gentle Gaussian blur should remove fine noise. To sharpen, create a duplicate layer and apply a gentle unsharp mask to it. If the image looks unnaturally over-sharpened, increase the transparency of the sharpened layer to blend it with the softer version beneath.



6 Increase contrast

You can increase contrast by copying the R channel from the step 1 image and pasting it as another layer on top of the RGB image. Change the new layer's Blend mode to 'Luminosity' and adjust the layer transparency to suit. Be warned: this may produce an unnatural end result.

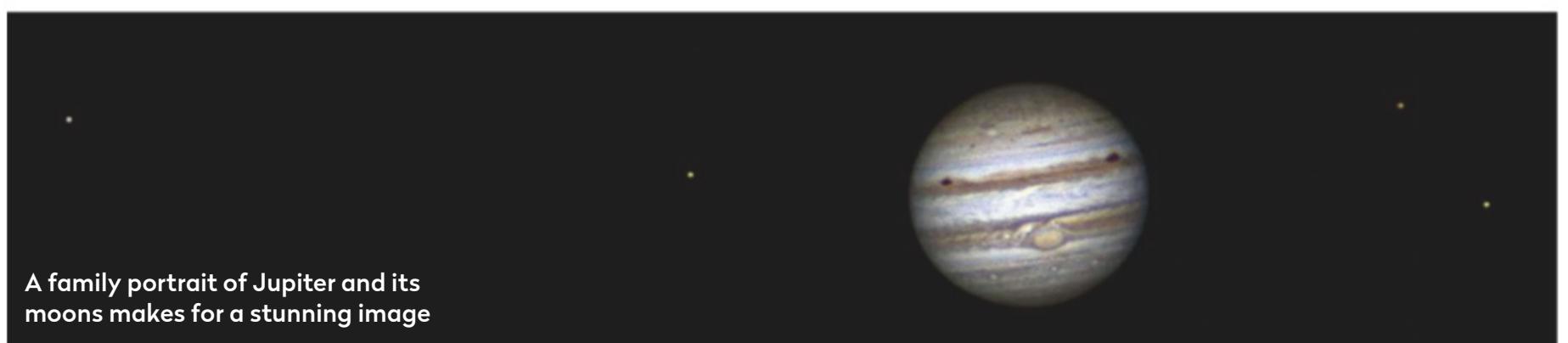
of the planet; they may, however, help to bring out detail that's difficult to see.

Once you get into the swing of taking filtered shots, you'll then need to consider how you're going to put them together. A little bit of thought may give you more options than you might initially think. For example, consider a single session where you've captured an RGB set – that

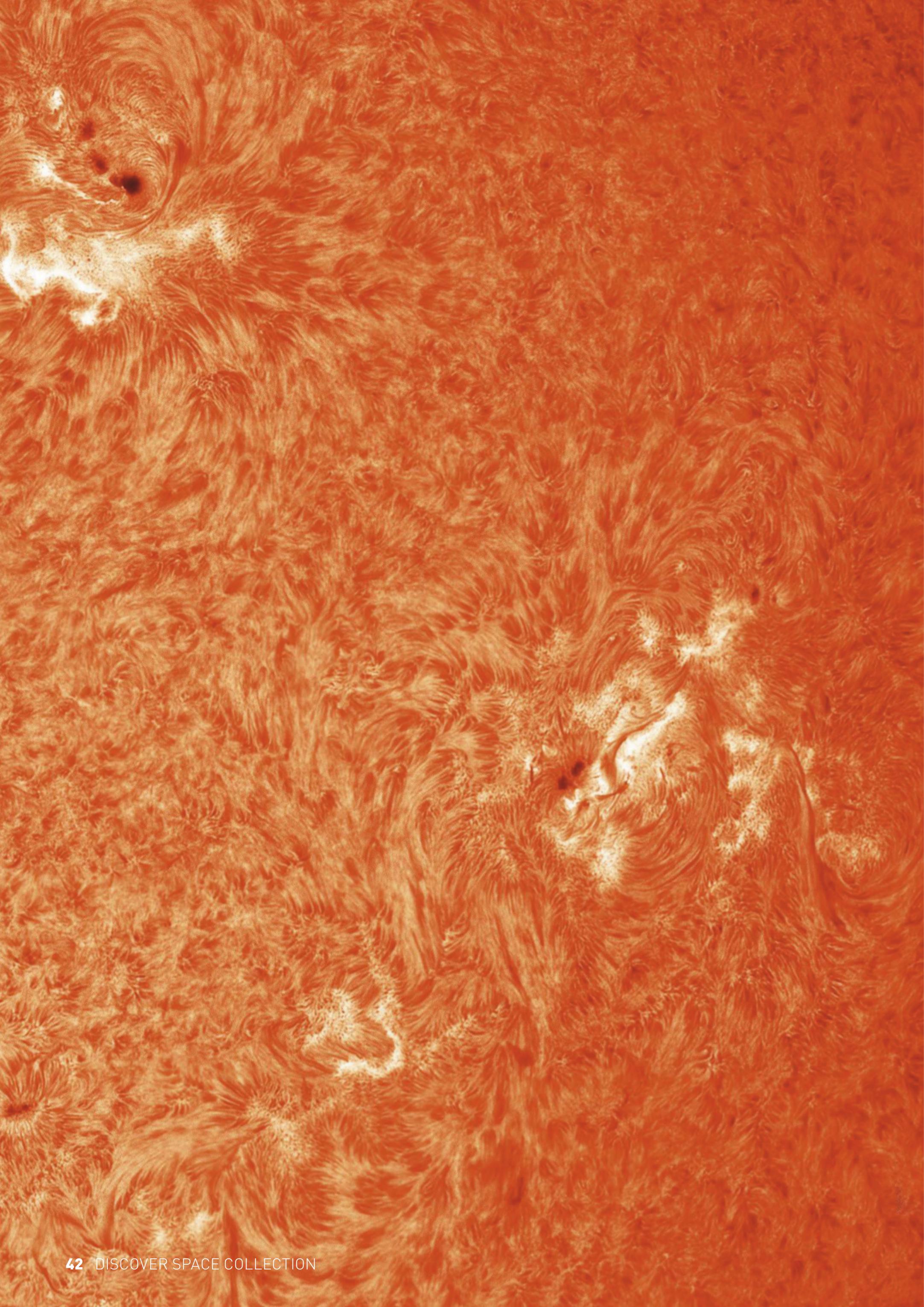
will give you one image. But if you take an RGBR set you can, in fact, get two images out of that by sharing the GB between both Rs. Similarly, if you're doing synth-green imaging, RBR will give you two completely separate colour results for just three image capture runs.

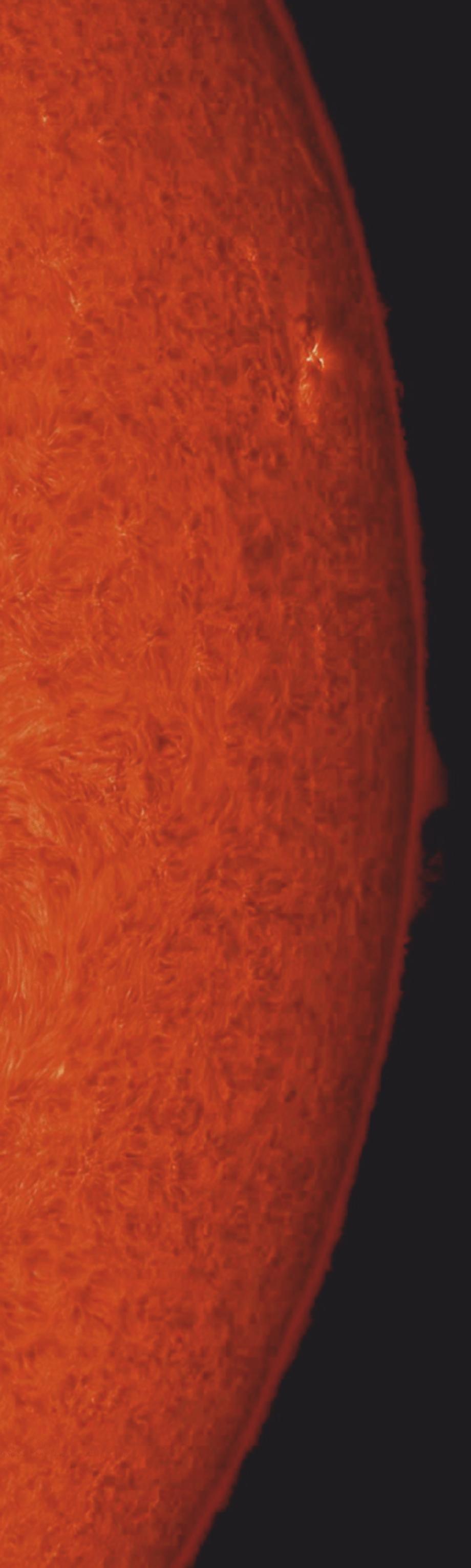
The basic principles for imaging Jupiter are similar to those for all of the bright

planets in the Solar System, although the others tend to be a little more forgiving in terms of capture time limits. Fortunately, Jupiter's brightness helps a lot, but this is definitely one area where a high-sensitivity, monochrome, high frame rate camera combined with the quick change capability of a filter wheel comes into its own.



A family portrait of Jupiter and its moons makes for a stunning image





◀ A 67-pane mosaic of the Sun imaged in H-alpha through a 102mm refractor using a Lumenera Skynyx 2-0M camera

SOLAR SAFETY

You should always use the correct kit to observe and image the Sun. Never look through or even point an unfiltered telescope at our star: you'll cause physical damage to both your eyes and the telescope.

Do not take risks by using uncertified filters. The golden rule is: if in doubt, don't do it.

THE SUN

There are several advantages to solar imaging, not least the opportunity to study a star. It's done during the day, when the temperature is normally quite pleasant and with plenty of light around, so you can say goodbye to fumbling with red-light torches. The amount of detail you'll capture depends on your kit, but there's usually something interesting to

see. Of course, there are downsides too. It can be difficult to see a computer screen in sunlight and there's a real danger from the intensity of light – it's one of the only times that astronomy can pose a risk of physical injury. Over the next few pages, we'll look at how to address these issues, what you can expect to see on our star and how to observe it safely. ▶

WHAT YOU'LL LEARN

44 Equipment

Find out how to capture the dynamic nature of our star in absolute safety

46 Technique

Learn how to exploit different wavelengths to see the Sun in new guises

48 Masterclass 1

We show you how to make a white-light filter for your scope and use it to image sunspots

50 Masterclass 2

Capture prominences and other features in hydrogen-alpha with a dedicated solar scope

OUR EXPERT



Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

PETE LAWRENCE

EQUIPMENT

From filters to scopes – all you need to capture the Sun

When taking images of the Sun it's important to use the right tools. The danger pointing a telescope at the Sun poses to your eyesight means that you should only ever use proper certified filters.

Solar telescopes come in two varieties – those that are dedicated to the purpose and those that have just been temporarily adapted for safe solar viewing. A standard, equatorially driven mount makes a perfect platform for either variety, since the Sun's motion across the sky is not significantly different from that of the stars.

White-light imaging involves removing most of the harmful light that could reach your camera sensor. There are various ways to do this, including projection, using a Herschel wedge inserted into the eyepiece holder or fitting a white-light filter over the front of your scope. Herschel wedges block most



You can view the Sun with a range of kit, from specialist solar telescopes to filtered instruments

of the harmful heat and light from the Sun, reducing its intensity to safe viewing levels but, like projection, is only suitable for use with refractors. The more flexible

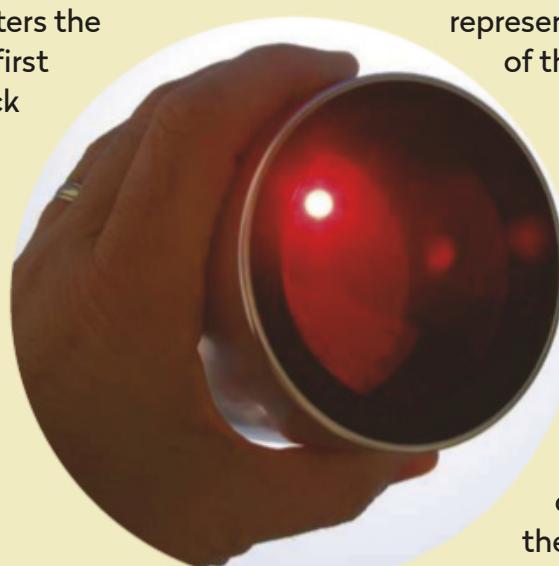
option is to use a white-light filter made from Baader AstroSolar Safety Film. This type of filter is easy to make and can be used with all telescope types. Never use cheap solar filters that fit onto eyepieces.

TECH TALK: How dedicated solar telescopes work

At the centre of many hydrogen-alpha telescopes is an optical device known as a Fabry-Pérot etalon. This creates an optical cavity by bringing two optically flat glass plates together, separated by a precise gap. The two parallel facing surfaces are semi-silvered. As light enters the cavity through the first plate, it reflects back and forth between the semi-silvered surfaces. The reflecting beams interfere with each other so that certain wavelengths reinforce while others cancel out – this is a process known as 'constructive and deconstructive interference'. The light

that eventually passes through the semi-silvered surface of the second plate contains bright wavelength peaks and dim wavelength troughs. A plot of wavelength versus intensity of this light looks a bit like an upside-down comb, the peaks being represented by the tips of the comb's teeth.

By passing the etalon's output through a less precise 'blocking' filter, it's possible to strip off all the unwanted 'comb teeth' and let just the one of interest through. The width of this peak defines the quality of the etalon and dictates how good a view you'll get at the eyepiece or camera.



▲ The etalon is the heart of many solar scopes

See it in a new light

A white-light filter will show groups of sunspots that appear to rotate across the solar disc over the course of a couple of weeks. But for really dramatic views you'll need a specialised narrowband filter that only lets a specific wavelength of light through, such as hydrogen-alpha, calcium-K, sodium or magnesium. They're more expensive than white-light filters and can only be used for solar work. Don't confuse deep-sky hydrogen alpha filters with solar ones – filters designed for deep-sky objects should never be used for imaging the Sun.

The cheapest hydrogen-alpha scopes are the Coronado PST and Lunt LS35, both of which have small apertures. A recent addition is the Daystar Solar Scout 60mm Double-Stack hydrogen-alpha telescope. Alternatively, the Daystar Quark series of eyepiece-end filters, which are available in chromosphere or prominence optimised hydrogen-alpha versions along with calcium-K, sodium and magnesium quarks. These open up the possibility of using larger aperture instruments

STEP BY STEP: Make a white-light filter



1 Gather your materials

You'll need thin, bendy card and thicker (1-2mm) card or mounting board to hold the film; solar film large enough for your scope's aperture; clear and double-sided tape; a pair of scissors or a craft knife; a compass; and a flat piece of tissue. Work on a flat surface away from draughts.



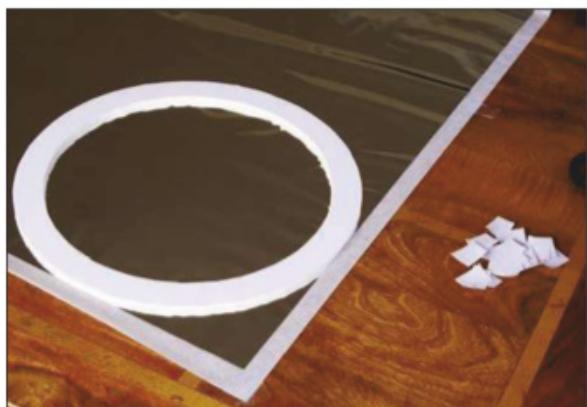
2 Prepare the card collar

Cut a strip of thin card 50mm wide and long enough to wrap around your scope. Use multiple strips if your scope has a very large aperture. Wrap the strip around your scope, fixing it with tape. Use double-sided tape to add a few more layers of strips on top to create a stiff collar.



3 Cut out a filter holder

Draw two concentric circles on the thicker card with a compass; one with the same external diameter as your scope's tube; the other with the same diameter as the scope's aperture. Cut around the two circles, then repeat to end up with two identical rings of thicker card.



4 Apply the film

Stick pads of double-sided tape around one side of each ring. Spread out the safety film on top of your work surface so it's flat and not wrinkled. Take one of the rings and peel off the protective layer from the tape. Place the ring straight down onto the film.



5 Create a filter cell

Cut around the ring to trim off the excess film. Peel the backing from the double-sided tape on the other ring and bring it together on the other side of the film to create your filter cell. Fit the collar to the scope, then position the cell, securing the two parts together using clear tape.



6 Adjust to fit

For a large-aperture reflector or Schmidt-Cassegrain, consider making a small, off-axis hole in another piece of card, positioned to avoid the secondary mirror or spider vanes. Secure it to your scope with electrical tape. Before use, hold the filter up to the Sun and check for holes.

– provided that you also use an appropriate energy rejection filter if your scope is larger than 3 inches. All have the potential to show prominences, filaments and spicules. Both hydrogen-alpha and calcium-K filters are available pre-fitted into dedicated solar telescopes or as kits

that can be used to convert night-time scopes for narrowband solar work. These can get pricey for larger apertures.

Whichever filter system you opt for, once it's been fitted, imaging the Sun is no more complicated than imaging the Moon. To capture the finest detail, a

high frame rate camera or planetary camera will produce the best results. For extra magnification, just use a Barlow lens. To fit the entire disc in the frame use a focal reducer, but note that this kind of smaller scale is only possible with certain telescope and camera combinations.

CAMERA CHOICE

DSLR

DSLR cameras are good for taking shots of the Sun through white-light filters, but not so good through narrowband filters.



Single images are also prone to atmospheric distortion.

High frame rate

As with other Solar System targets a mono, high frame rate camera will produce the best results, especially when used with narrowband filter systems.



The high frame rates these cameras can achieve are ideal for reducing seeing effects.

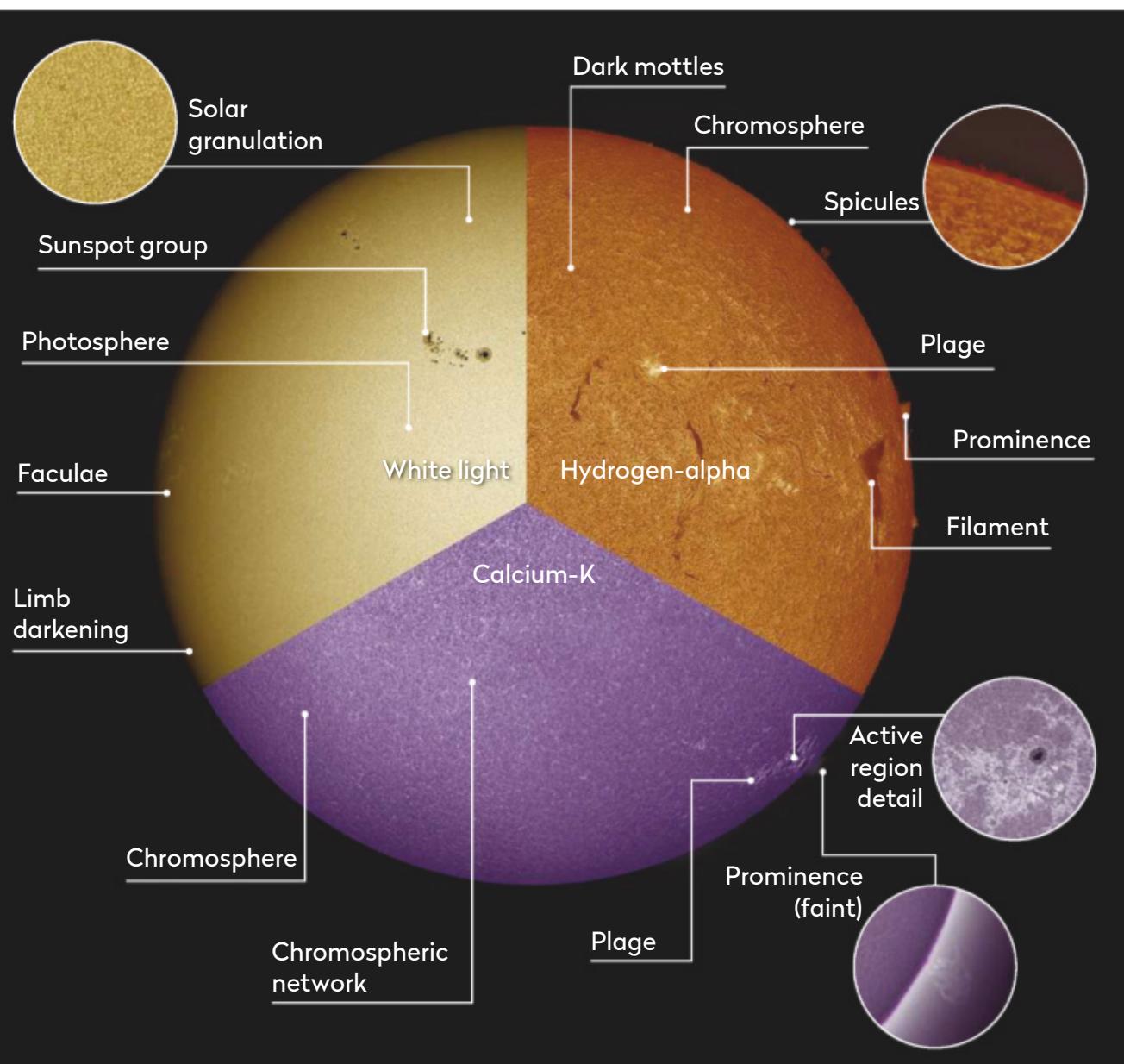
Cooled CCD

A monochrome cooled astronomical CCD camera can work well with narrowband-filtered images. The best technique is to take lots of short-exposures and stack them together using a program such as RegiStax.



TECHNIQUE

Tips and tricks for successful solar imaging



▲ From faculae to filaments: what to look for on the Sun with three types of solar filter

The techniques used to image the Sun are similar to those used to capture images of the Moon and planets. The difference is that the intensity of the light from the Sun must be reduced. There are different filter systems to do this and it's important only to use certified ones.

The best camera for imaging the filtered Sun, especially if you intend to use any magnification, is a monochrome high frame rate camera. Colour devices work for white-light captures, but they may be lacking when using speciality filters as their built-in colour filters can reduce the sensor's sensitivity.

Solar imaging falls into two categories: white light and narrowband. White-light imaging reduces the amount of sunlight to safe levels, cutting out harmful, invisible wavelengths. With a white-light filter on the front of your telescope, the

Sun's fearsome output is dimmed to levels that are safe enough for imaging. The white-light filter allows you to capture the Sun's visible surface, which is known as the photosphere.

Finer optics

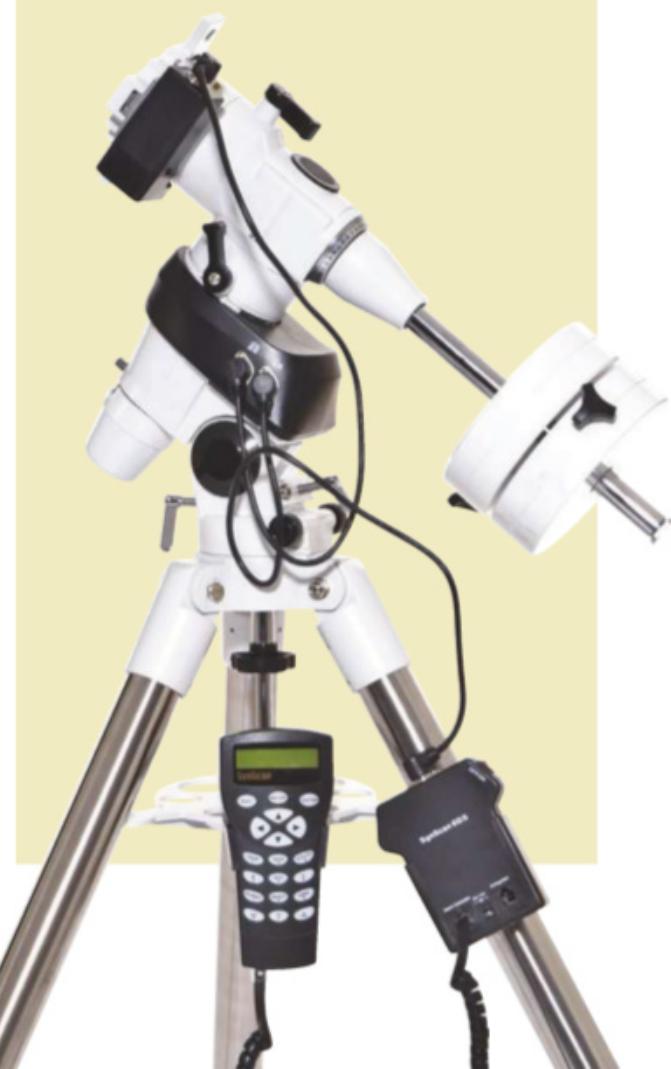
Narrowband imaging is completely different. It calls for filters that are typically much more expensive than a basic white-light filter. The reason for this expense is down to the very fine optical tolerances that need to be met in order for the filters to work.

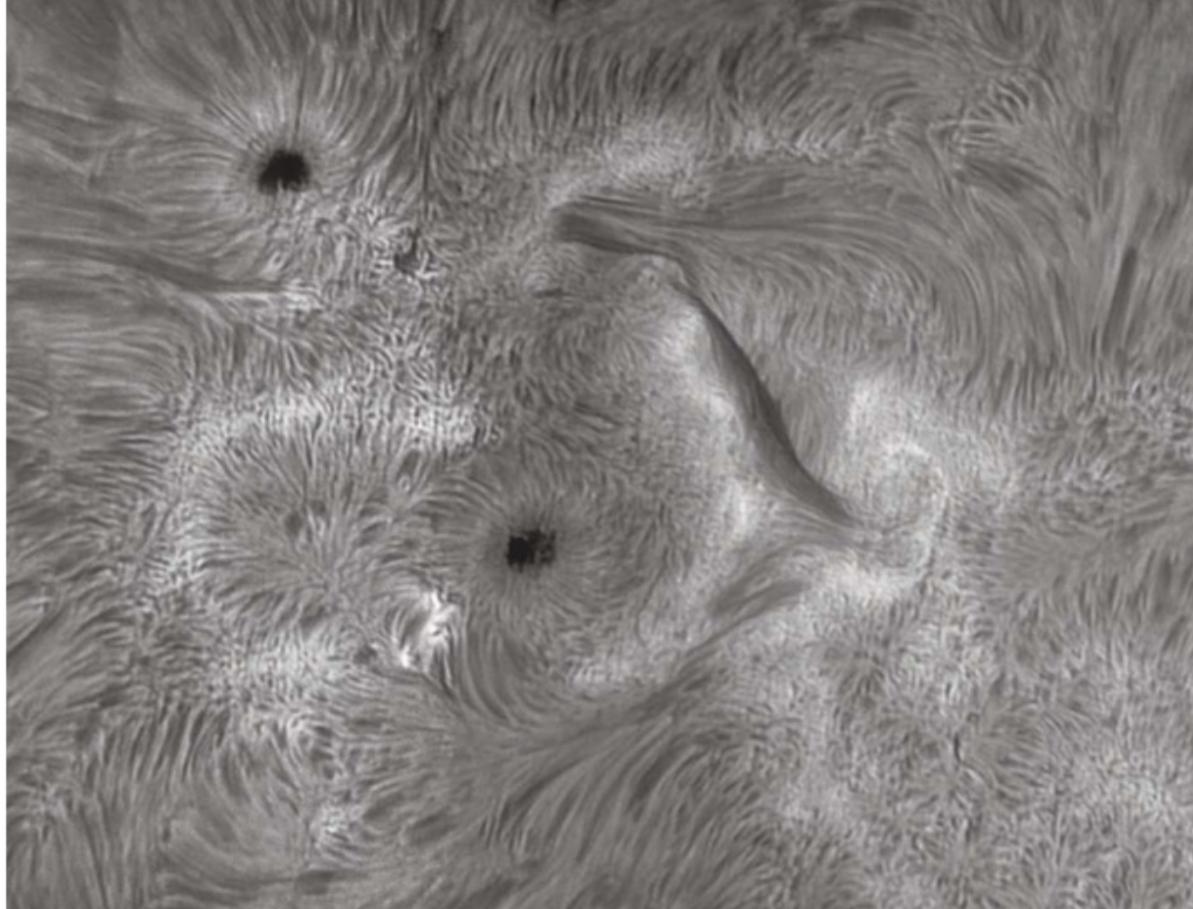
The main narrowband filter types used for solar imaging concentrate on hydrogen-alpha light, which has a wavelength of 656.3nm, plus calcium-K light with a 393.4nm wavelength. Less common filters include those that work with the 589.6nm wavelength of sodium-D light.

How good a narrowband filter is can be measured by how wide its 'window' of extra wavelengths is, which lets light through either side of the central wavelength. This is also known as bandwidth. Narrowing the bandwidth allows ever-finer surface detail to be picked out. A low-cost hydrogen-alpha filter, like one from a Coronado PST, has a stated bandwidth of less than 0.1nm. Bandwidths can get narrower, to 0.05-0.03nm and this is where the cost

TECH TALK: Which mount?

Solar imaging at low magnification is possible using a fixed mount, but a driven and polar-aligned equatorial mount will make life much easier. While the Sun's apparent motion across the sky isn't exactly the same as that of the stars, it is close enough not to have to worry about it during a typical imaging session, and a standard right ascension drive will do a perfectly adequate job. As with any other type of imaging, a stable, heavy-duty mount is highly recommended to help avoid any unwanted wobbles.





▲ A hydrogen-alpha monochrome image of the Sun revealing filaments in the chromosphere

comes in: filters with windows this narrow can cost many thousands of pounds. Stacking two matched filters on top of one another, a technique known as double stacking, can also help reduce bandwidth.

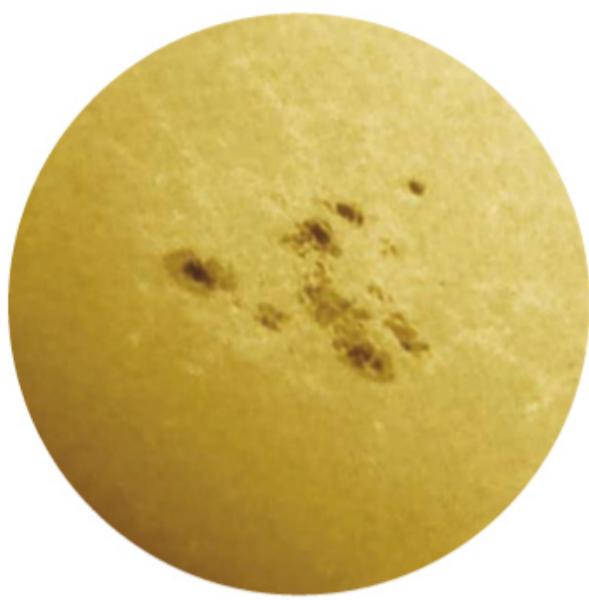
We've said that imaging the Sun is no more complex than imaging the Moon, and while this is generally true, the lack of fixed features on the Sun's disc can lead to confusion – especially in relation to its orientation in the sky. Fortunately, if your

scope sits on an equatorial mount, the solution is pretty straightforward. Begin by rotating the camera so that any features visible move parallel to the bottom edge of the imaging frame when you slew your scope in right ascension.

The north edge of the Sun is found by using a finger to apply gentle upward pressure to the front of the tube. The last edge of the Sun that would be visible if this motion were continued would be its northern edge if you're in the northern hemisphere, or southern edge if you're in the southern hemisphere.

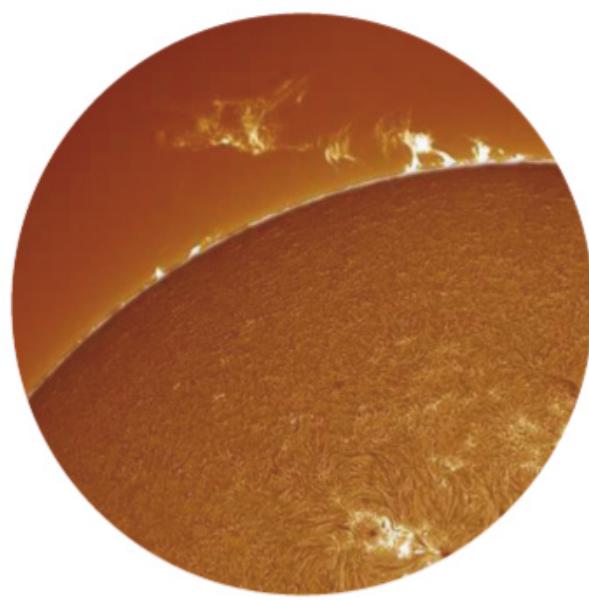
Finally, apply a similar pressure to push the tube over to the west. Again, the last edge of the Sun that would be visible if the motion were continued would be its western edge. Note that the Sun's axis tilts relative to Earth and changes throughout the year. Freeware program TiltingSun (www.atoptics.co.uk/tiltsun.htm) can help you visualise this tilt when you come to image the Sun.

PRO POINTER: Three popular wavelengths to view the Sun



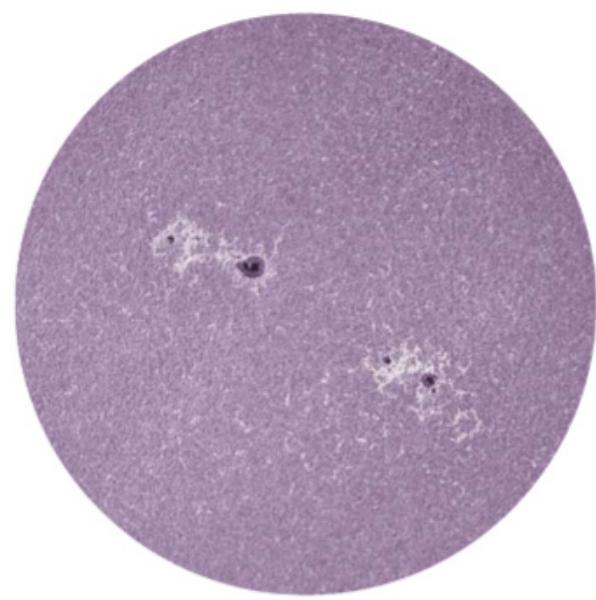
White light

A white-light view reveals the Sun's visible surface, the photosphere. With good seeing, a 4-inch or larger scope will reveal the photosphere's mottled texture. Called solar granulation, this looks a bit like lots of rice grains packed together. The photosphere looks darker at the edge of the disc due to a phenomenon known as limb darkening and it's here that you might find bright patches called faculae. If the Sun is active, there may be sunspots on view too. Larger spots typically appear in groups called sunspot groups, pictured, or active regions. A typical sunspot has a dark centre known as the umbra, surrounded by a lighter region known as the penumbra.



Hydrogen-alpha

Through a hydrogen-alpha filter, the photosphere is hidden under a blanket of hydrogen known as the chromosphere – only light from this layer gets through. Dark mottles formed by jets of hydrogen are known as fibrils. Seen edge-on at the Sun's limb, the fibrils look like tiny spikes and are called spicules. Active regions are marked by huge swirls of hydrogen tracing intense magnetic field lines, in and around which plage appear. Where magnetic tension erupts, there are vast releases of energy from bright flares. Snake-like clouds of hydrogen known as filaments float above the chromosphere. When at the edge of the Sun, they are known as prominences.



Calcium-K

A calcium-K filter reveals detail in a low part of the chromosphere, just above the photosphere. Consequently, the view is not dissimilar to that seen through a white-light filter. There are, however, some subtle differences – a calcium-K filter is very good at bringing out detail in and around active regions. Bright areas called plage can be seen in these regions and remain visible across the Sun's disc. Solar granulation is hidden from view, but the calcium-K Sun does show a large network of bright interlocking paths known as the chromospheric network. Bright prominences may also be imaged as they extend off the edge of the calcium-K Sun.

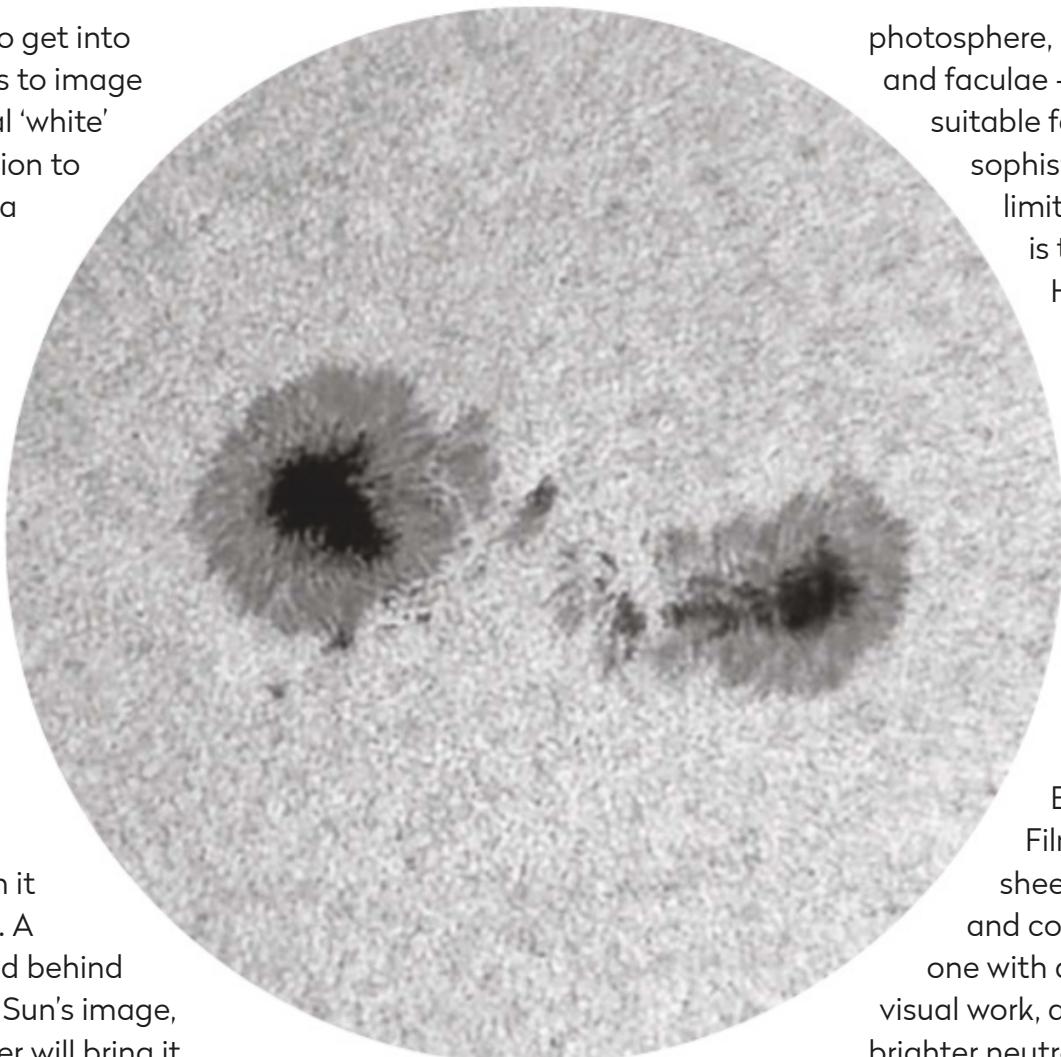
MASTERCLASS 1

See sunspots with projections and white-light filters

An inexpensive way to get into solar photography is to image the Sun in its natural 'white' light. When you pay attention to the safety issues, it can be a very rewarding way to monitor our nearest star.

One of the most basic methods is to use solar projection. For this you'll need a small refractor, ideally mounted on a driven equatorial mount. With your scope pointing away from the Sun, fit a non-plastic, low-power eyepiece and ensure the finder is removed or capped. Watching the scope's shadow on the ground, turn it to point directly at the Sun. A piece of stiff white card held behind the eyepiece will catch the Sun's image, while a tweak on the focuser will bring it into sharp relief. A card shield taped to the objective end of the tube may help improve contrast if the projection is difficult to see.

Now set your camera to automatic and take a shot of the image on the card screen. If the image comes out too



▲ Sunspots as seen using a white-light filter; the dark centre is known as the umbra

bright, try moving the screen away from the eyepiece or, if you have manual controls, try underexposing the shot. This basic method is capable of showing the

photosphere, limb-darkening, sunspots and faculae – it is, however, only suitable for refractors. A more sophisticated method, also limited to use with refractors, is to use a device called a Herschel wedge inserted in the eyepiece holder. The wedge stops most of the harmful heat and light from the Sun, reducing its intensity to safe viewing levels. A more universal method that is suitable for any type of telescope is to use a white-light filter. You can make one yourself from Baader AstroSolar Safety Film, which is available in A4 sheets. These cost around £20 and come in one of two types: one with a neutral density of 5.0 for visual work, and one with a slightly brighter neutral density of 3.8 for imaging. Larger 100x50cm sheets are also available, or you can buy a white-light filter from Thousand Oaks Optical.

With a filter fitted you can image the Sun just as you would the Moon. In fact, the same constraints apply because the Sun's light is just as susceptible to our

TECH TALK: Finding focus

Focusing is a critical skill to master in any form of astronomical imaging. If you're just starting out, accurate focusing can be quite hard to get to grips with, which can make the whole imaging experience rather frustrating. There's no reason why this needs to be the case, so here are a few tips on how to get your images as sharp as possible.

First, make sure your camera is securely locked into your telescope's eyepiece holder and that the focuser tension adjustment is set firm. You want to be able to move the camera back and forth quite easily, but you also want it to stay where you've put it. Locate a high-contrast part of the Sun. For

white-light imaging, the best target is the Sun's edge. For more exotic filters, the Sun's surface is normally detailed enough for you to lock onto that. Even here, though, it's good practice to choose a sunspot group or a dark hydrogen-alpha filament to give you a better focus target.

Gently move in on focus, getting slower as you appear to be reaching the critical point. When you reach it, keep going until you pass through it. Then reverse direction, passing slowly through focus, this time from the other side. Do this a few times until you can recognise the real point of focus, then adjust the focuser until you're in that position.

Practise zooming in and out of focus...

...to produce a crisp image

SEEING AND THE SUN

Earth's turbulent atmosphere interferes with sunlight on its way to your telescope, making fine detail on the Sun's surface appear to wobble and distort. This is known as 'seeing'. The Sun's own heat can make matters worse, causing heat thermals as the day starts to get going. For white-light imaging, poor seeing means the difference between viewing solar granulation or not, so it's a good idea to choose periods when the seeing is good. Mid to late morning is often ideal because it's before the Sun's heat has had a chance to take full effect.



▲ Poor seeing can result in the loss of granulation in white light images

turbulent atmosphere. DSLR cameras are good for low-power shots, but high frame rate planetary cameras are more suitable for close-ups. Screwing a solar continuum or green imaging filter onto your camera's nosepiece may enhance contrast in detail and granulation. The files created by high frame rate captures are processed in the same way as lunar or planetary ones: by sending them through a stacking program such as RegiStax or AutoStakkert.

STEP BY STEP: Imaging the Sun in white light



1 Fit your filter

With the scope pointing away from the Sun, remove its lens cap and fit the solar filter; remove or cap the finderscope too. Make sure everything is securely fastened. If required, use some electrical tape to hold the filter in place securely – this is vitally important on windy days.



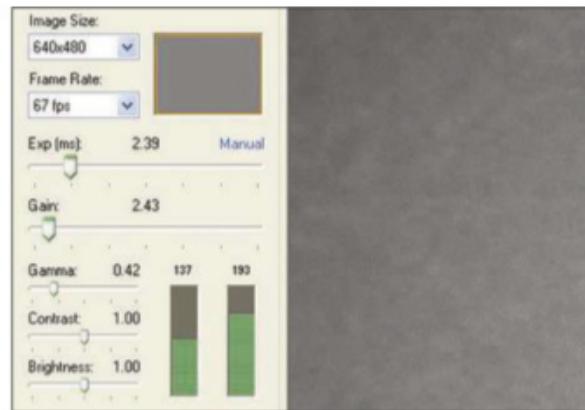
2 Line up with the Sun

Lining the telescope up with the Sun without using a finderscope isn't hard. Without looking along the tube towards the Sun, roughly align the scope and then look at its shadow. As the scope approaches the correct alignment, the tube's shadow will reach minimum size.



3 Keep it in the shade

If you find it hard to see detail on your computer screen in sunlight, you'll need a dark enclosure. A simple one can be made with a blanket, but for something more sturdy try placing your laptop in a closed cardboard box with a slit cut in it so you can see the screen.



4 Insert your camera

If you have one, screw a solar continuum or green imaging filter onto your camera. Insert the camera into the eyepiece holder of your scope and fine-tune the scope's position so that an image can be seen on your computer's screen. Locate the Sun's edge and focus roughly.



5 Settings and focus

Using the highest frame rate, reduce gain and exposure until the image is correctly exposed and contains no white. You may need to use a neutral density filter. Rotate the camera so any spots move horizontally across the frame when slewing in right ascension. Finally, focus the image.

6 Capture

For low magnification setups showing all, or a large portion, of the Sun's photosphere, aim to capture 500-800 frames. Increase this to around 2,000 for larger magnifications. If your software lets you, reduce gamma to make granulation and spot detail easier to see.

MASTERCLASS 2

Hydrogen-alpha imaging with a Coronado PST



▲ Hydrogen-alpha shots often reveal huge prominences leaping off the Sun's limb and show just how dynamic the surface of our nearest star can be

The Coronado PST has revolutionised hydrogen-alpha solar observing because it's both cheap and portable. But as far as imaging is concerned there are a few hiccups, mainly due to a lack of inward movement when focusing high frame rate cameras. This results in you being

unable to reach prime focus, hindering the scope's usefulness for solar imaging.

But there are solutions. One of the easiest is to take the front lens off a standard 2x Barlow and screw it into your camera. The view isn't quite prime focus, but it's not far off and focus can generally be reached. You can also buy



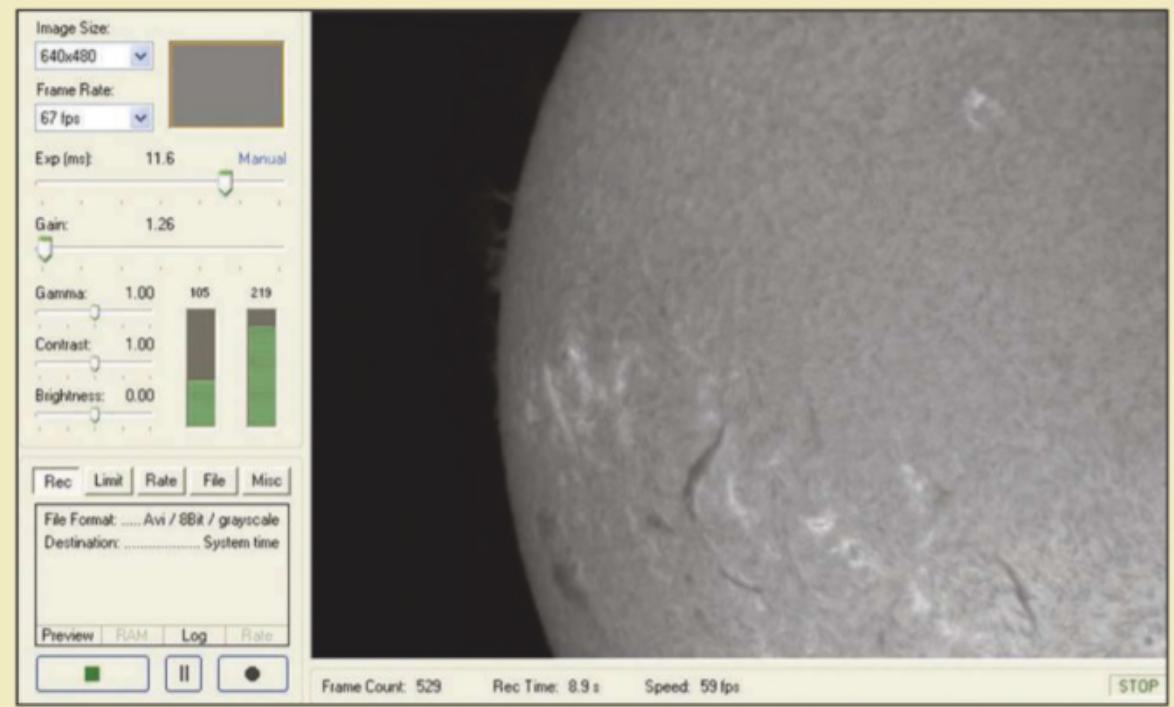
▲ A Coronado PST is a compact, portable and affordable solar telescope

a low-profile nosepiece that puts the camera closer to the eyepiece holder.

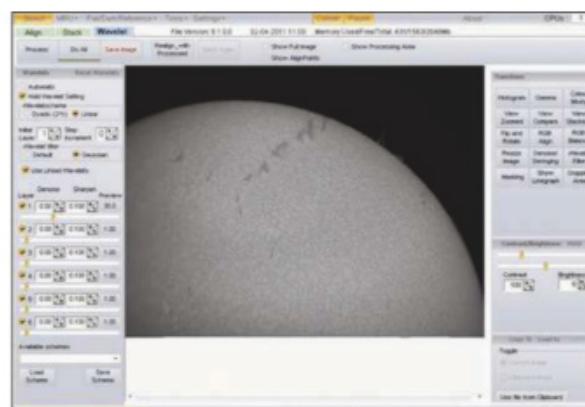
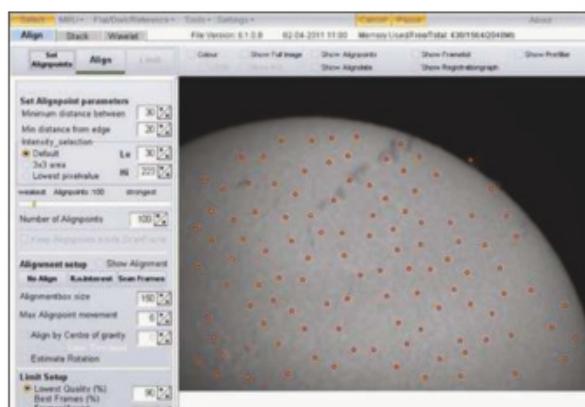
The PST is a low-power instrument. Its 40mm objective works at f/10, giving a focal length of 400mm. Consequently, image scale tends to be quite modest and the PST is excellent for overview shots of the Sun's disc. In terms of the

TECH TALK: Adjusting your camera settings

Different camera control programs can have different setting options, but the most common settings are exposure, gain, gamma, contrast, brightness and frame rate. Typically, gamma, contrast and brightness should be left at their zero (default) levels. It might be tempting to adjust gamma down to improve surface detail clarity but, in reality, this can be emulated using a graphics editor after image capture. Exposure, gain and frame rate need to be adjusted so that you get a strong signal at the fastest frame rate possible. If you can keep the gain as low as possible to achieve this, you'll also reduce the level of noise.

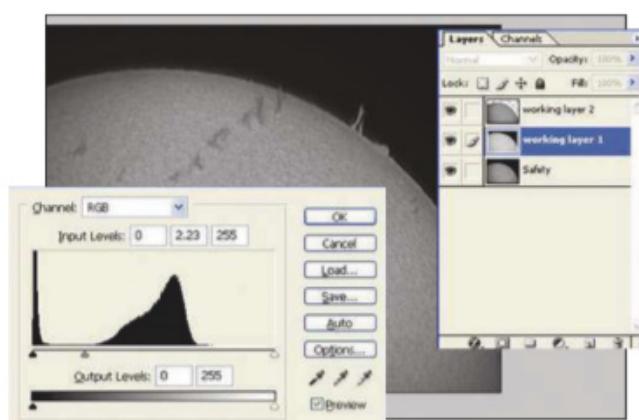


STEP BY STEP: Refine and sharpen your images



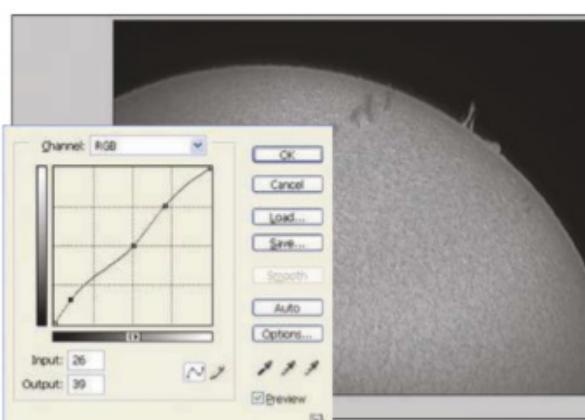
1 Load in RegiStax

Pass your files through a program such as RegiStax or AutoStakkert. In RegiStax 6, select your capture file, click Set Alignpoints and then Align. Drag the bottom slider to include the best frames on the RegiStrationgraph and click Limit. Click Stack to finish.



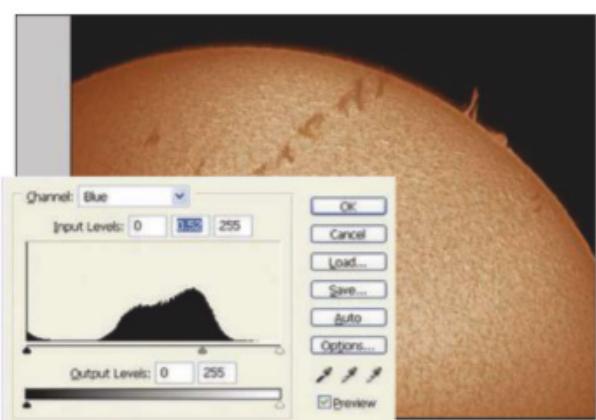
2 Use wavelets to sharpen

Wavelets can sharpen your images. A typical PST result responds well to Wavelet-scheme: Linear and Wavelet-filter: Gaussian. Check Use linked wavelets and set the first slider to 30. Once you've found a scheme that suits you, save it via the Save Scheme button.



3 Save and load

Save your processed result as a 16-bit PNG or TIFF file and load it into a layer-based program such as Photoshop. If necessary, crop the image to remove any white borders that may have appeared. Duplicate the base layer for safety and work on the duplicate layer.



4 Enhance solar features

For images of prominences and the solar surface, duplicate the working layer and activate the top layer. Select everything in the sky down to the curved limb. Expand, feather the selection by two pixels, delete it and deselect. Make the lower layer active. Adjust the mid slider.

5 Tweak the layers

Tweak the surface (top) layer using the curves adjustment tool. A contrast tweak can also help. If applicable, tweak the prominence layer in the same way. Try to keep the join between surface and prominences as natural as possible. When you're happy, merge them.

6 Apply false colour

Make sure the mono image is in RGB mode and open the levels tool. Move the red channel's mid slider towards the black (left) end of the histogram. Move the green channel's mid slider the same way, but move the blue channel's mid slider towards the white end of the histogram.

"The PST is excellent for overview shots of the Sun's disc. In terms of the camera, a monochrome high frame rate model is best"

camera, a monochrome high frame rate model is best. Colour cameras are fitted with a matrix of colour filters that severely reduces sensor sensitivity when working at one specific wavelength.

The PST is threaded for a standard photographic tripod, but if you can mount it on a driven equatorial mount you'll find things a lot easier. With the scope mounted, use its shadow on the ground to point it roughly at the Sun. Fine pointing can be achieved by getting the bright spot (a small Sun image) in the

centre of the PST's built-in solar finder. You can then look through a low-power eyepiece in the PST's eyepiece holder to finish off the job, if this proves necessary.

Screw the lens from a 2x Barlow into your camera and attach it to the PST's eyepiece holder. You should be able to see a (probably unfocused) image on your laptop – place a blanket or cardboard box over your head and laptop if you have trouble seeing the screen. Carefully focus using the thumbscrew at the base of the PST's body (see 'Tech

Talk', page 48). Don't worry about exposure – just make sure the Sun's edge and any visible prominences are as sharp as possible.

Once you've found focus, set your camera's gamma, contrast and brightness to their zero (default) settings. Using the highest frame rate available, decrease the gain and then the exposure so that the surface appears detailed but not overexposed – there should be no white showing. If the image is dim to start with, begin using a lower frame rate. Rotate the PST's tuning ring so that you achieve maximum hydrogen-alpha contrast in the centre of the image. For the low image scale (magnification) images that the PST offers, aim to record 500-800 frames per capture.





◀ 1,500 lightyears from Earth, the Horsehead Nebula is a fascinating target for budding deep-sky imagers

THE DEEP SKY

Deep-sky astrophotography is perhaps the most demanding of all the subjects covered in these pages. What we've covered so far involves capturing bright objects that respond well to short exposures, but deep-sky objects tend to be relatively dim. Capturing enough photons to produce clear, detailed and noise-free images of these

far-off targets requires long exposures that will stretch the capabilities of your camera and place great demands on your mount, in terms of its ability to track accurately. In this introduction, we'll provide tips and techniques to help you get the most from your kit. We'll show you the best way to set up your gear, capture the data and process it to create stunning images.▶

WHAT YOU'LL LEARN

54 Equipment

Find out which cameras you need to image deep-sky objects and why your mount is the most important asset

56 Technique

Learn how to prepare your instrument for imaging and how to shoot calibration frames

58 Masterclass 1

Slew your telescope and camera towards globular cluster M13 for your first taste of deep-sky imaging

60 Masterclass 2

Master the secrets of imaging nebulae in colour with our NGC 7000 tutorial

OUR EXPERT



Steve Richards is a seasoned deep-sky imager and *BBC Sky at Night Magazine's* Scope Doctor

ISTOCK

EQUIPMENT

Sharp images need a steady tripod and a solid mount

You might think that the most important piece of equipment you need for deep-sky imaging is the telescope or camera. In fact, it's the mount. Tracking deep-sky objects and taking long exposures of them as they traverse the night sky places great demands on your mount, so it needs to be up to the job.

First of all, you will need an equatorial mount for accurate tracking. Although an altazimuth (altaz) mount is just about suitable for high frame rate lunar and planetary imaging, it doesn't quite make the grade for deep-sky work. The reason for this is simple: an equatorial mount will follow celestial objects in a smooth arc across the sky, whereas an altaz mount follows the same object in a series of horizontal (azimuth) and vertical (altitude) steps. This stepping movement will result in the image rotating around the centre of the frame (as depicted in the two diagrams at the bottom of page 55) resulting in star trails and a blurred image.

Your mount must be as substantial as possible too. Any unwanted movement will result in blurred images and ugly star

shapes; even the wind can have a detrimental effect. Although you won't require a Go-To mount, it's vital that your mount is motorised, at least in the right ascension (RA) axis, so it will smoothly track the movement of the sky. While it's nice to have a motorised declination (dec.) axis, it isn't essential. If you're accurately polar aligned, you can track using a motorised RA drive alone.

The minimum grade of mount that we'd recommend for deep-sky imaging would be an EQ3 or its equivalent, and then only if you're using a camera and small telephoto lens. The most popular mounts for astrophotography are the HEQ5 and (N)EQ6-type mounts.

As important as the mount is the tripod on which it sits. This should be rock solid and, ideally, the legs should be made from tubular steel rather than the flimsy extruded aluminium of lightweight mounts. You want to provide a stable platform to your camera and optics so they can



◀ A solid mount, like this Sky-Watcher EQ6-R PRO Synscan mount, lies at the heart of successful deep-sky imaging

CAMERA CHOICE



DSLR
DSLR cameras are self-contained and equipped with large sensors, and also suit non-astro purposes. Their built-in infrared filter tends to be a little too wide in its coverage, though and this can diminish the amount of important, red hydrogen-alpha (H α) light you can capture from emission nebulae.

Colour CCD
One-shot colour CCD cameras are designed for deep-sky imaging, they sport a filter-free sensor with a Peltier cooling system to reduce 'noise' generated by the electronics. They come in a range of sensor sizes and, like DSLRs, capture colour in a single shot – ideal for the UK's fickle weather.

Mono CCD
Mono CCD cameras take great greyscale images. If you want to take colour images, things get a little more complicated: this involves taking different sets of exposures using red (R), green (G) and blue (B) filters and then combining them in software to produce a final RGB colour image.

get on with their job with the minimum of interruption.

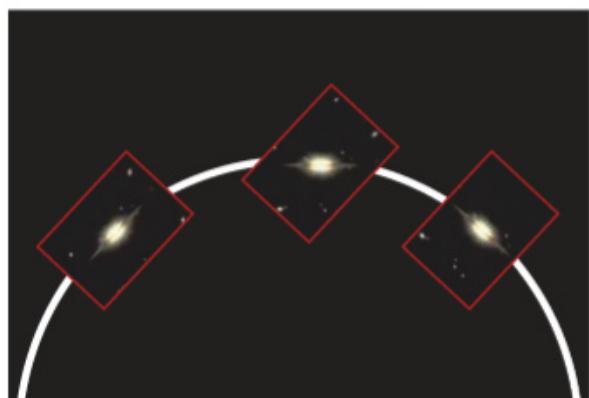
Smooth operator

Before beginning an imaging session, ensure that your RA axis turns smoothly with no binding and that there's a minimum of backlash in the gears. Check also that the clutch mechanisms lock the RA and dec. axes solidly so that there's no slippage, and that the attachment method for the telescope is secure.

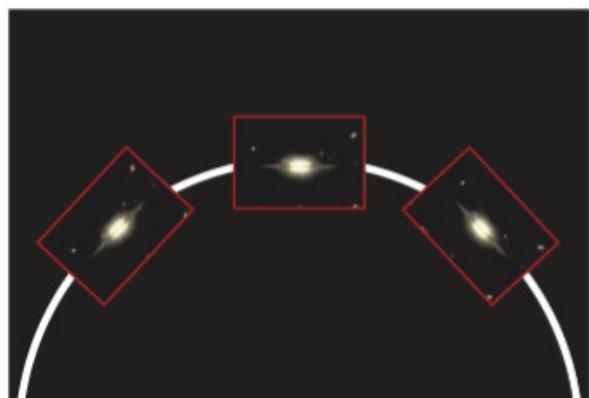
If your mount doesn't come with a polarscope as standard, you'll need to add one, as accurate polar alignment is vital for good quality results. A polar-aligned mount will make locating objects much easier, especially with a Go-To system.

It's a common assumption that you need a large and powerful telescope for deep-sky imaging. In fact, since many deep-sky objects are rather large, smaller, short focal length telescopes with their wider fields of view can be very effective, especially for regions of nebulosity that are particularly extensive.

Although the old adage "there's no substitute for aperture" is valid for observing deep-sky objects, it's not quite so important for imaging, as you can compensate for smaller apertures with longer exposures. The larger the telescope, the greater the loading on the mount; the heavier the load, the more work the mount will have to do to track properly. Longer focal lengths will also put greater demands on a mount's



▲ With an altazimuth mount the field rotates



▲ With an equatorial mount the field is static

TECH TALK: Connecting your kit

All this equipment needs to be connected, and although DSLR camera manufacturers use different bayonet fittings for their lens attachments, there is, luckily, a standard fitting called a T-mount.

T-mounts have two sides: a female 42mm-threaded insert (a T-thread) and a camera-specific bayonet. This allows a DSLR camera to be attached to a range of astronomy-related items, including the focus tubes of many telescopes. Most CCD cameras have a T-thread built into them.

A simple T to 1.25-inch (or T to 2-inch) nosepiece adaptor allows any camera to connect to the eyepiece holder of any telescope. Achieving focus with a refractor after the star diagonal has been removed from the

▼ Both sides of the T-mount (bottom) and a 2-inch nosepiece extension tube (below)



focuser usually requires a T-extension tube. However you attach your camera, make sure it can't flop about, as it's vital the camera performs as one with the telescope.

tracking abilities. Small tracking errors are amplified by long focal lengths, so choose your telescope carefully to get the most from your system and to ensure that your mount and telescope are well matched.

If your main interest lies in galaxies and globular clusters, then their relatively small apparent size will mean that a longer focal length telescope is a good choice to capture them in detail, so consider a Schmidt-Cassegrain instrument or Newtonian reflector. Quite often, though, these objects do look great in a wider field of view, which enables you to see them in a wider setting.

If your interests are more nebula-based, then a short focal length refractor would be a good choice. Many deep-sky imagers find a 3- or 4-inch refractor perfect for the purpose. The advantage of using a small refractor is that it will place fewer demands on your mount, both in terms of load-bearing and tracking performance. This is why many established imagers recommend these instruments to people starting out on the imaging road. If your

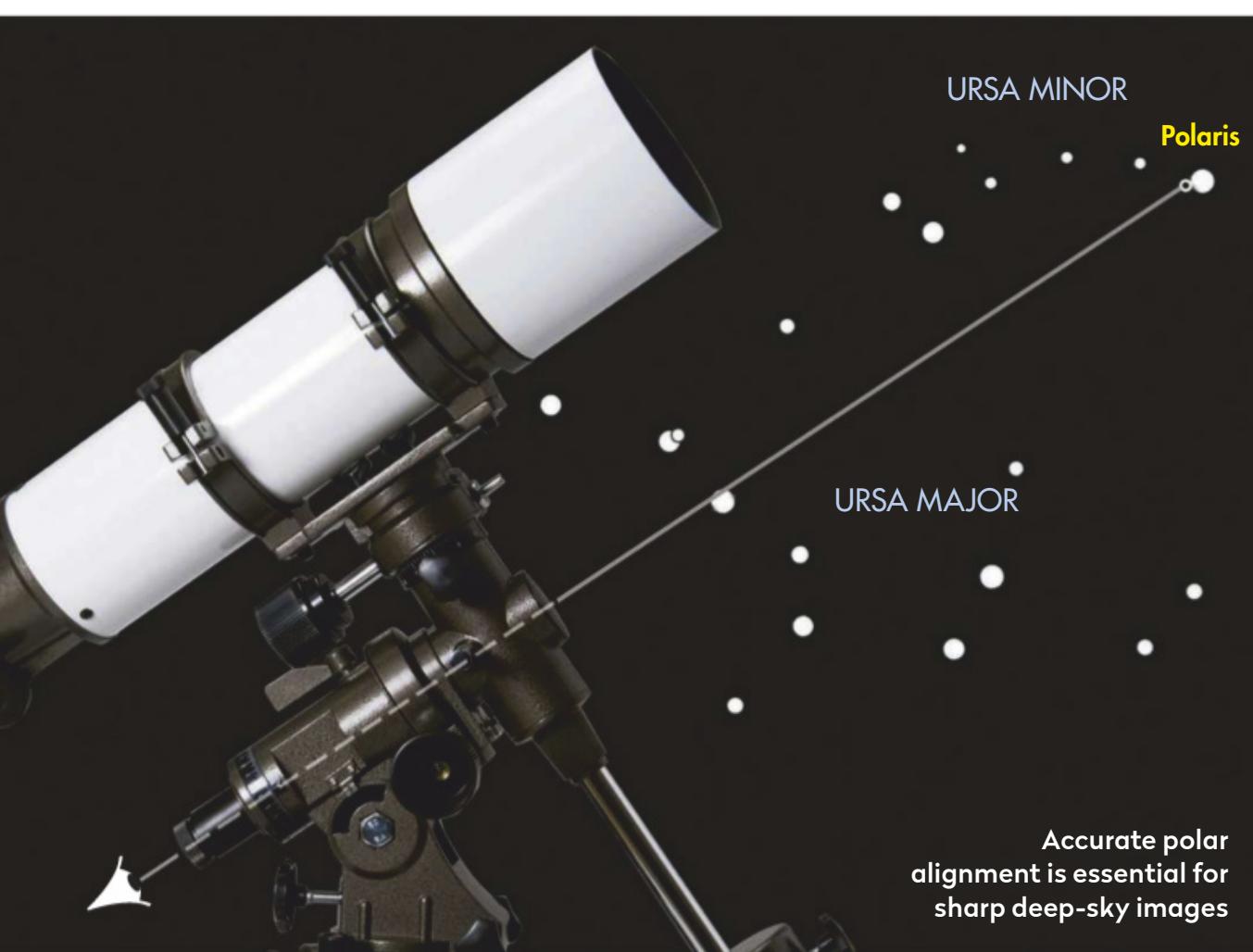
interests are polarised between planetary or lunar observations and deep-sky imaging, a Schmidt-Cassegrain with a focal reducer-field flattener (see page 68) will cover a lot of ground.

▼ Consider a small refractor (below) for nebula imaging or a Schmidt-Cassegrain for galaxies and globular clusters (bottom)



TECHNIQUE

Preparation is the key to successful imaging



Deep-sky imaging is all about preparation. Once the frames start rolling, your work outside is pretty much done and you can keep an eye on the system while you sit back and enjoy the night sky.

The first task is to set up your telescope's tripod and mount so that they're facing north and the tripod's top is reasonably level, although this doesn't have to be perfect. Next you should adjust your mount's altitude setting to match your own latitude using the two adjustment bolts at the front and rear of the mount, being very careful to release one while tightening the other.

You can now carry out the vital polar alignment routine using your mount's built-in polarscope. Read your mount's manual, since there is some variation between manufacturers in how this is done. Don't skip the part about calibrating your polarscope: this only needs to be done once but it's key to the success of future polar alignments. What you're attempting to do is get a distant object centred on the polarscope's crosshairs irrespective of where the right

ascension (RA) axis is rotated, as this ensures that the polarscope is accurately aligned with the RA axis.

Moving in circles

The rest of the polar alignment process makes use of the setting circles, which act as a circular slide rule to calculate the position of the star Polaris at your location, date and time. Adjust the mount so that Polaris appears in the polarscope eyepiece's reticle in the correct position. As an alternative you can use a smartphone app to show you where Polaris should appear through the polarscope.

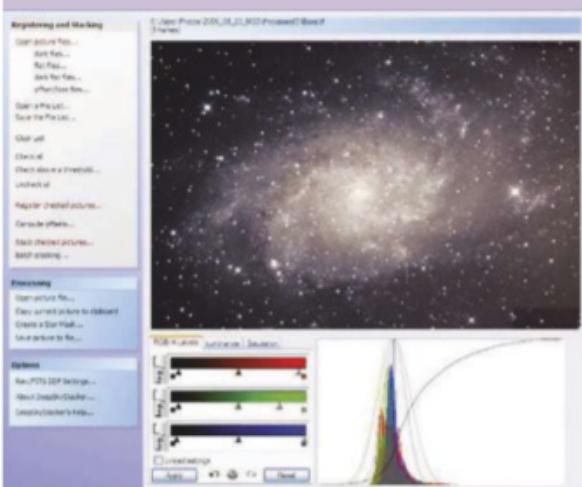
Once you have polar alignment you should install the counterbalance weights, followed by your telescope and camera. Rotate the RA axis until it's horizontal to the ground, roughly adjust the position of the counterbalance weights until they balance the telescope, then lock the RA axis clutch. Carefully adjust the position of the telescope's dovetail bar until the telescope and camera are well balanced from front to rear. With the declination (dec.) axis

TECH TALK: Control software

CCD cameras have no controls. Instead they rely on software running on a computer to set exposure times, cooling temperatures, resolution settings and so on. Most CCD cameras come with basic proprietary software to perform these functions, but usually there's an ASCOM driver supplied as well to allow a range of camera control programs to be used. Sequence Generator Pro, MaxIm DL, AstroArt and Nebulosity are the most popular and have extra features, such as image sequencing to automate the capture process.

DSLR cameras can be operated as standalone imagers, most simply by using a plug-in intervalometer to capture a sequence of timed exposures, but it's increasingly common to use camera control software instead. The software mentioned above works with many DSLR cameras, and BackyardEOS and ImagesPlus are also popular choices.

Whatever type of camera you use, your subframe images must be calibrated and then stacked to produce the best signal-to-noise ratio in your finished image. Along with the previously mentioned software, PixInsight, Astro Pixel Processor and DeepSkyStacker are popular choices for combining this type of image for final processing.



▲ DeepSkyStacker is a free, downloadable application that registers and stacks images

accurately balanced, make final adjustments to the counterweights to achieve a perfect balance in the RA axis. It's worth rechecking the polarscope to ensure you haven't moved it out of alignment while adding the equipment.

If you have a Go-To mount, adjust it to the 'Park' position – counterbalance weights down and telescope pointing up – and carry out a one-star alignment, choosing a star as close as possible to the object that you want to image. With the telescope aligned on this star, make good use of it by focusing accurately using a Bahtinov mask. This is simply a mask with a specific pattern of cut-outs in it that attaches to the front of your telescope. It's designed to match your telescope's aperture and focal length, and the cut-outs produce a set of diffraction spikes on a bright star that appear as an X-shaped cross with a line through it. By adjusting the focus until the line exactly bisects the cross, you can be assured of a perfect focus every time.

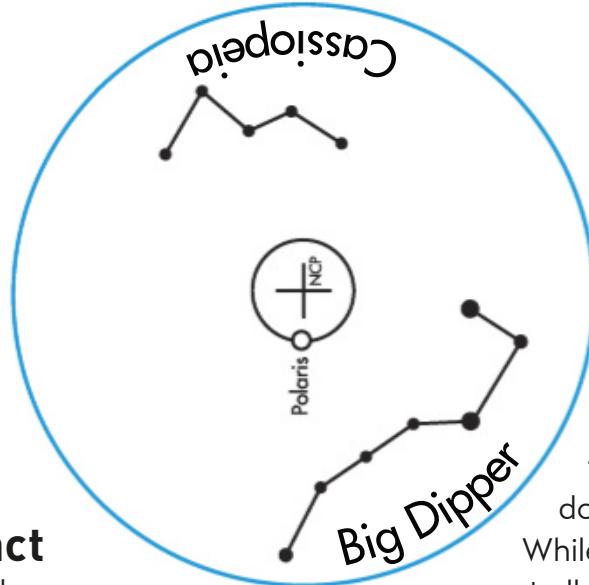
To achieve focus, take an image, check it on your camera's preview screen or on your laptop monitor and adjust the focus

as necessary, repeating until you're happy with the result. Slew to your chosen object or, if you're not using a Go-To mount, star-hop to find it.

Unbalancing act

Now you're going to do something counter-intuitive and unbalance the mount slightly. Stand on the south side of your mount facing north and check which side of the mount the weights are located. If they're on your right, slide them 2cm down the counterbalance shaft; if they're on your left, slide them 2cm up the shaft. This ensures the RA axis is always being driven and doesn't teeter between idling and moving.

Now start your imaging run, taking a whole set of images at the same exposure one after the other. Depending on your subject, you may also wish to take some shorter exposures to use later



▲ Position Polaris in the correct place in your polarscope's reticule

to fill in any burnt-out areas of your image.

How you frame your image – what aspects should be in it and where they should lie in the frame – is entirely down to personal taste.

While you don't necessarily want all your main objects perfectly centred in the frame, you will want to show your image at its best, so getting the framing right makes sense and also avoids the need to crop your image later in the imaging process.

Several planetarium programs have a useful feature that allows you to enter the dimensions of your system's field of view and then overlay a matching rectangle on top of your chosen object to decide the best camera orientation. You simply need to rotate your camera to this orientation before you start.

Once you have captured your light images, you should capture a set of bias, dark and flat calibration frames.

PRO POINTER: The importance of calibration frames

Once you have collected all your image data, known as light frames, you'll need to take three additional special sets of subframes to calibrate your image. These calibration frames remove unwanted artefacts from your image.

The first set, bias frames, are very easy to take – simply cap your telescope to exclude any light and take 20 or so exposures at your DSLR camera's fastest shutter speed, or use the 'Bias' option if you have a CCD camera. These frames are subtracted from your light frames and compensate for variances between the output from individual pixels. They also remove any read-out noise generated in the light frames.

The next set, dark frames, are also taken with the telescope capped, but

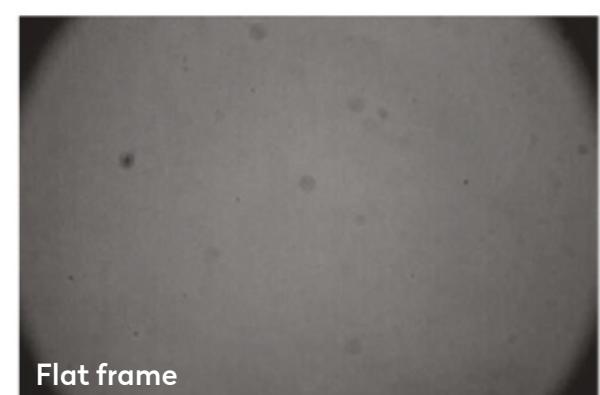
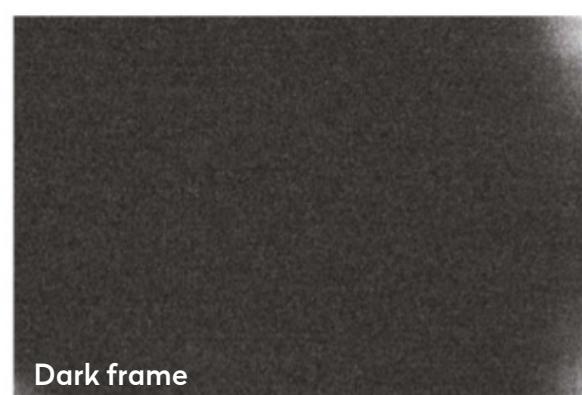
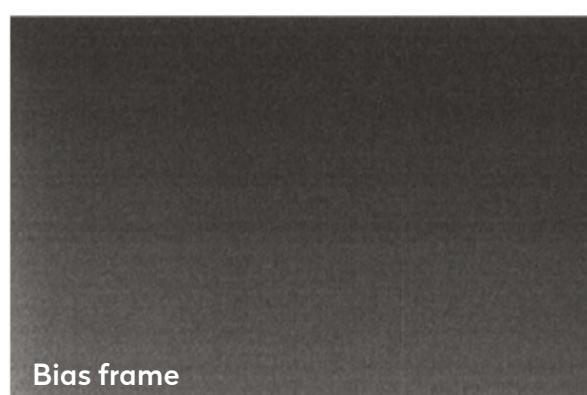
with exactly the same exposure length as you used for your light frames. You should take 10 or more, and these are also subtracted from your light frames to remove the effects of heat generated by the sensor and any amplifiers in your camera.

The last set, flat frames, are the most fiddly to take but they can make a dramatic improvement to the quality of your final image. Flats are taken at exactly the same focus position and camera orientation as your light frames. These exposures are then divided into the lights to compensate for vignetting – a reduction in sharpness at the edges of the frame caused by the optical design or by obstructions to the light cone. Flats also remove the doughnut-shaped

smudges caused by dust particles at various points in the light path.

There are various ways of taking flats, from photographing electroluminescent panels through to taking shots of a diffuse light source (such as the sky) with a white T-shirt over the front of the telescope. With a DSLR camera, set the imaging mode to 'Av' and take about 20 images. With a CCD, take the same number of images but aim at an overall illumination of between 30 and 50 per cent of the maximum saturation level.

Once you've collected these calibration frames, you can use processing software to apply them to your light frames automatically, then stack your images to produce a final, calibrated image. We show you how on page 106.



MASTERCLASS 1

Now you're ready for your first deep-sky target,
point your scope at globular cluster M13

A single, 65-second sub-frame
of globular cluster M13



The calibrated, de-Bayered
and stacked image of M13



STEVE RICHARDS X 9

For this masterclass we'll show you how to capture an image of globular cluster M13, a popular astrophotography target in the constellation of Hercules. You can use a one-shot colour CCD or a DSLR camera for this as you won't need to worry about hydrogen-alpha emissions. If you're using

your DSLR on its own then 'Live view' is particularly useful when focusing.

Focus your camera on mag. +2.8 Zeta (ζ) Herculis, the star at the bottom right of the Keystone asterism in the centre of Hercules. Remove your Bahtinov mask, if you used one, and slew up towards mag. +3.5 Eta (η) Herculis at the top

right-hand corner of the Keystone. M13 is found two thirds of the way between these two stars.

The cluster's apparent diameter is 20 arcseconds, so a focal length of 650-1,200mm would be ideal – well within reach of many popular reflector and refractor telescopes. A smaller focal

CAMERA SETTINGS

DSLR

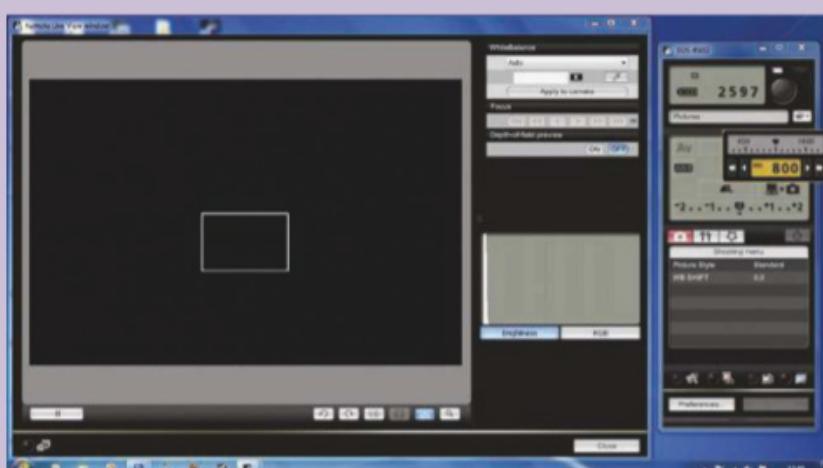
If your camera's hardware allows you to take exposures of a minute or more, use it to set the ISO value to 1,600, white balance to auto, file format to raw,

noise reduction (if available) to off and shutter speed to 60 seconds. If not, set these values manually, then set the shutter speed to bulb and use a manual or programmable remote-shutter-

release cable to trip the shutter for a 60-second exposure. There's no aperture setting because telescopes don't have a variable iris. If your software doesn't allow a live view image on your laptop, take a series of 10-second exposures using a Bahtinov mask and adjust the focus between shots.

CCD CAMERA

Although CCD cameras need software to control them, some have a gain control. But use this with caution to avoid increasing noise levels from the camera's sensor. Set the exposure to between 100 and 120 seconds for the imaging run, but for focusing on a bright star, six-second exposures with 2x2 binning will suffice. Unlike a DSLR, there's no image processing built in, so images are automatically taken in raw. If you have set-point cooling, set it to 25°C below the ambient temperature and set the binning mode to 1x1.



◀ Adjust focus using remotely operated software such as Canon's EOS Utility

STEP BY STEP: How to image M13



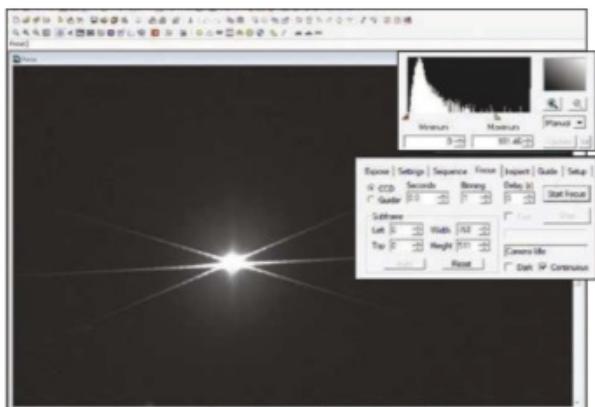
1 Polar alignment

To ensure that your mount tracks the sky as accurately as possible and to help your Go-To system to locate objects first time, carry out an accurate polar alignment. Using a polarscope is quick and easy, so don't compromise – this will be a little time well spent.



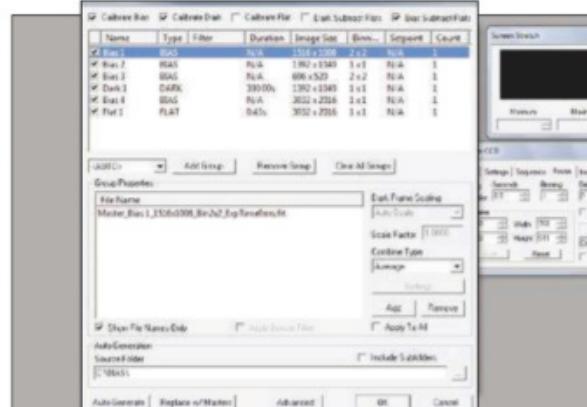
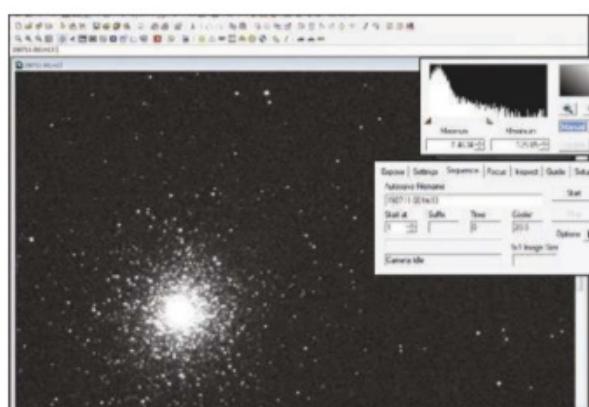
2 Getting balanced

Your mount will work best if you limit the amount of load it has to move. Getting an accurate balance will go a long way to achieving this. Balance the declination axis first with all of your equipment installed and the camera at approximate focus, then balance the right ascension axis.



3 Lock on

Align on a bright star near Hercules such as Vega, fit your Bahtinov mask and adjust focus until the cross is bisected by the line. Remove the mask and slew to Zeta Herculis, centring it on your camera's sensor. If your mount can do so, synchronise on this star and slew to M13.

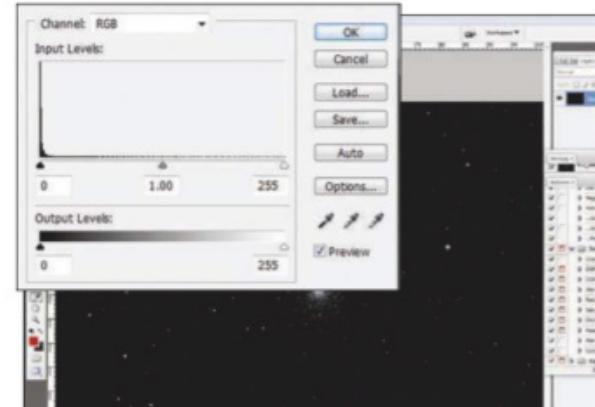


4 Capture

Start your imaging run, aiming for as many images as possible. Unless you already have a library of bias and dark frames (at the correct exposure length), leave time for these. Flat frames must be taken on the night or the next day without touching the camera or focus.

5 Calibrate and stack

Using your stacking software, apply your calibration frames to your image data to remove unwanted artefacts. Unless your software does this automatically, de-Bayer your calibrated frames and stack them using the SD Mask or Kappa Sigma option.



6 Post processing

You should be seeing a reasonable image, but this is just the starting point. Export your image as a TIFF file (8-bit or ideally 16-bit) and load it into your preferred image editing software. Start applying a gentle levels adjustment to release detail in your image.

length may not work as well, as globular clusters lose their visual impact if the field of view is too wide. Framing isn't too critical for this circular object but you might want to include the two contrasting colour stars in your image – blue to the south and reddish to the east – or even mag. +11.6 NGC 6207, a spiral galaxy, to the northeast.

Bright to the core

M13 is fairly bright at mag. +5.9 but it has an intense core, so you'll need to be careful not to overexpose it and burn out the centre. Exposures in the region of 60 seconds at an ISO of between 800 and 1,600 for a DSLR camera, or 120-150 seconds with a one-shot colour CCD camera, should capture some good detail.

Take at least 10 images (but preferably around 30) at these settings, using Raw mode on your DSLR or unbinned if you're using a CCD camera.

You can automate the process with the software that controls your CCD camera, but if you're using a DSLR camera without a laptop, a programmable remote-shutter release, known as an intervalometer, will do this for you. Using an intervalometer will also help you avoid camera shake, since you won't have to push the shutter release button. Complete the session by taking 16-20 dark frames, bias frames and, if possible, flat frames.

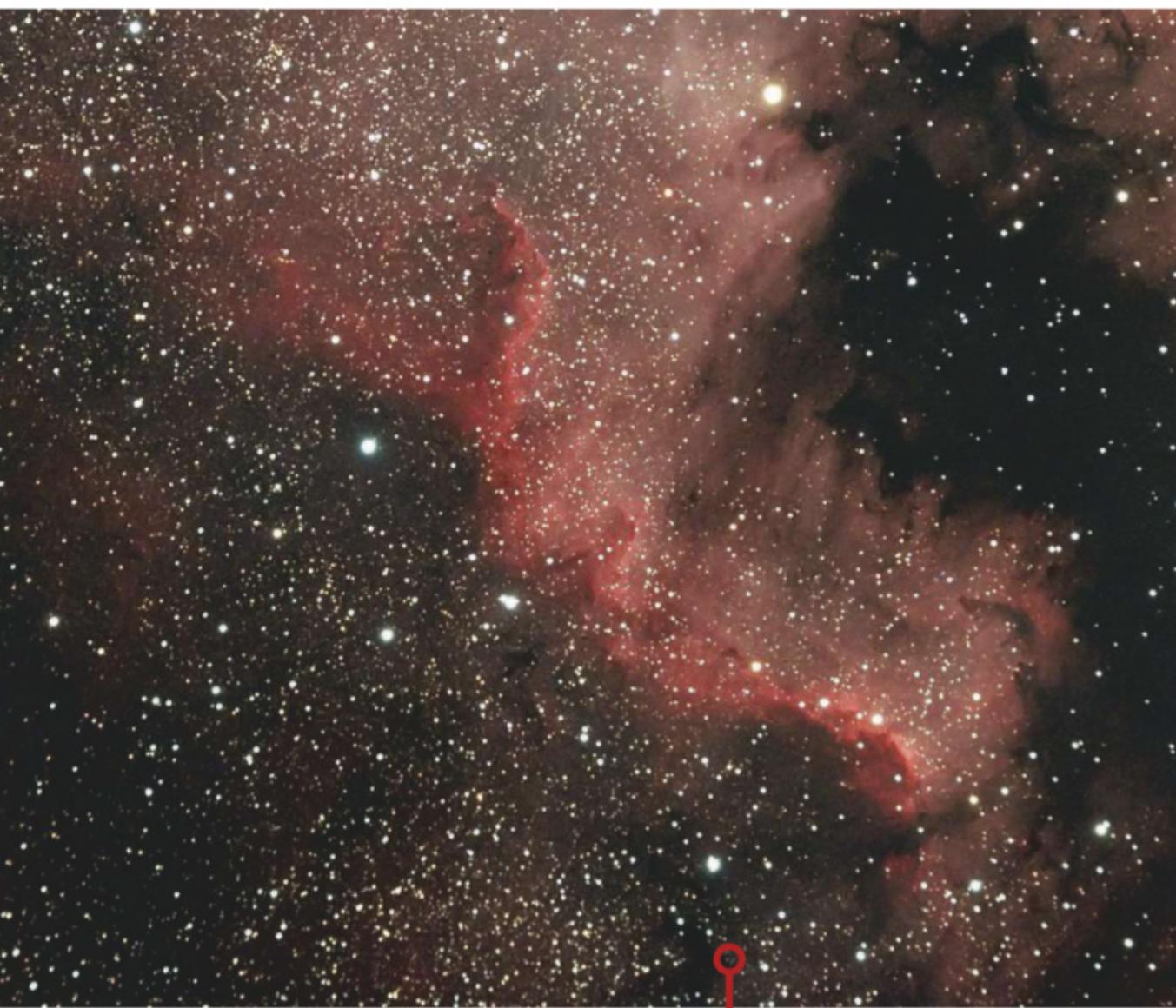
Using suitable software such as MaxIm DL, PixInsight, Astro Pixels Processor or DeepSkyStacker, you should now calibrate and stack your images.

DeepSkyStacker will import your light, dark, bias and flat frames and automatically carry out the various processing tasks for you to give a calibrated, de-Bayered (to generate the colour channels captured by the Bayer filter) and stacked image ready for importing into a photo-editing program such as Photoshop or GIMP.

MaxIm DL, on the other hand, will break the process down into modules. The first operation stacks the calibration frames into master frames. These masters will then be applied to each of your light frames. Save the result in a new folder if you wish. Stack the calibrated light frames to produce a final FITS-format file, then save a copy in TIFF format for final processing in Photoshop or GIMP.

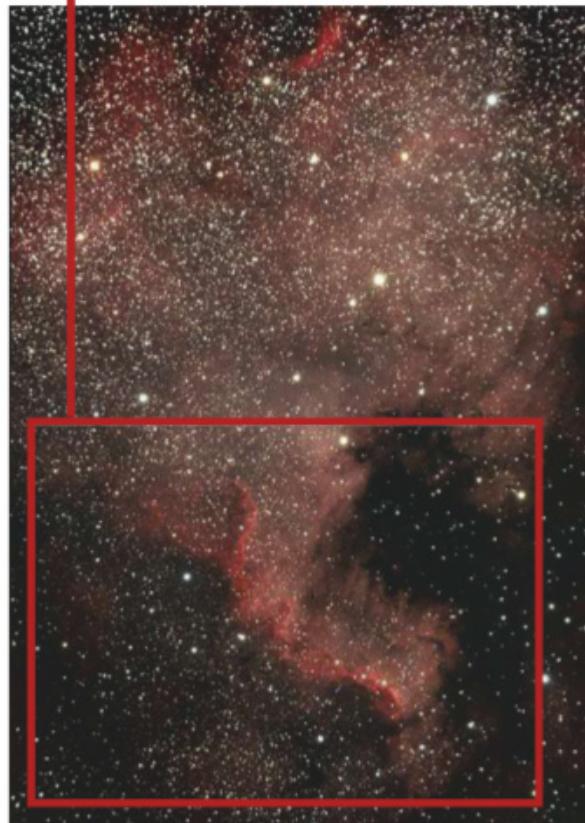
MASTERCLASS 2

Capture the rich detail of the North America Nebula in glorious colour with the help of a hydrogen-alpha filter



Building on the techniques learned in the previous masterclass, we're going to tackle a very different object – an emission nebula in the Milky Way. Emission nebulae can be quite extensive, so you'll need a short focal length telescope and a large sensor to capture the whole area of nebulosity. Don't worry if you don't have such a setup, though, you can still zero in on smaller sections.

NGC 7000, or the North America Nebula, is rich in hydrogen-alpha (Ha) emissions, so getting the best from this object will require a modified DSLR or a CCD camera. DSLR cameras have a built-in infrared filter, which unfortunately filters out the very Ha wavelength that you want to capture from these objects. Many imagers have their camera modified to remove this filter. CCD cameras, on the other hand, are supplied



▲ The Wall is an area at the foot of NGC 7000 (Mexico below the US and Canada) that contains a region of star formation

PRO POINTER: Add extra luminance

Detail in an image is held in the luminance (L) channel and is embedded in the RGB channels. But you can add extra luminance data to your colour image to produce more fine detail.

A good way of doing this with an emission nebula is to use a hydrogen-alpha (Ha) image as the luminance channel. Capture the data with a Ha filter using a mono CCD camera, a one-shot colour CCD binned at 2x2 or even a DSLR camera. But simply adding a luminance channel using Ha data will result in muted colours, due to a mismatch in contrast between it and the RGB data. To resolve this, blend the Ha data with the red channel.

Start by pasting the Ha image onto the red channel. Use a 50 per cent opacity setting and align the two. Then, adjust the opacity of the Ha layer until you get the most pleasing greyscale image. Once you're satisfied, flatten the image and replace the red channel in the original RGB image with your new Ha-enhanced red channel. You'll now have a more detailed Ha+RGB image to admire.



BEFORE



AFTER

unfiltered so are already suited to imaging Ha-rich areas.

It's very important to get the framing right, so use your planetarium software's reticle overlay feature to decide the best sensor orientation for the whole nebula. If you can't fit the whole nebula in your telescope's field of view, concentrate on the section known as 'The Wall', situated at the foot of the nebula. You can calculate your sensor-telescope combination's field of view by using our online calculator at www.skyatnightmagazine.com/field-view-calculator.

Error correction

The surface brightness of NGC 7000 is less than M13's, so you'll need longer exposures to capture the detail and colour. We'll look at how to autoguide

your scope over a long exposure in the next section ('The Deep Sky – Advanced', starting on p62), but if your mount has a Periodic Error Correction (PEC) function, use it to help your tracking accuracy.

PEC is a system that lets you record a set of corrections (that you make) to where your telescope points during a complete cycle of the gear system, while keeping a test star centred on a crosshair in your eyepiece. These corrections are then 'played back' repeatedly while the mount is tracking, to remove any errors introduced by any small imperfections in the drivetrain. These errors are called 'periodic' because they repeat again and again during the same period of time.

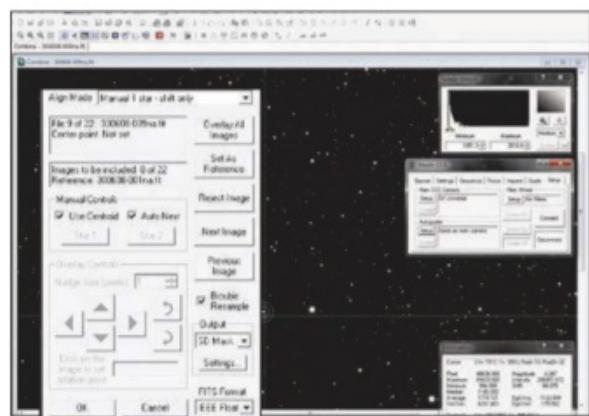
Take as many 200-second exposures as you can, although be prepared to discard some of them due to poor

tracking. Even though you have carefully polar aligned, balanced the mount and are using PEC, there will be some tracking errors that are not periodic in nature and these could cause elongated star shapes. It is only through guiding your mount, either manually or automatically, that you can be pretty sure of making every frame count. If you're not fully confident, don't worry, just keep reading – there's more to come on autoguiding (p64).

If you're going to use a mono CCD camera, use an infrared filter, if possible, to help tame bloated stars. If you have one, why not try an Ha filter too? This will capture some very fine detail in NGC 7000 and will make the most of the increased sensitivity of a mono CCD.

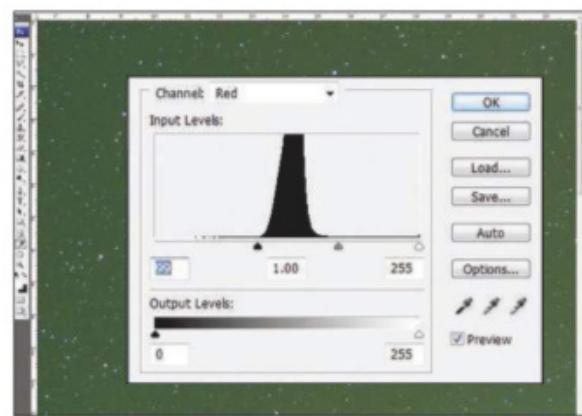
Lastly, regardless of which camera you use, don't forget you'll need to shoot calibration frames.

STEP BY STEP: How to process your shots of NGC 7000



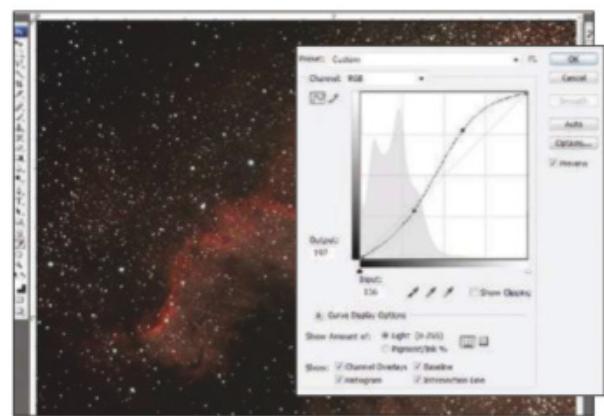
1 Calibrate, stack and save

Apply your calibration frames in the same way as you did for your M13 image, but in the case of a mono CCD camera, you won't need to de-Bayer your data. Stack your calibrated frames as before and save the resulting image as both a 16-bit FITS and a 16-bit TIFF file.



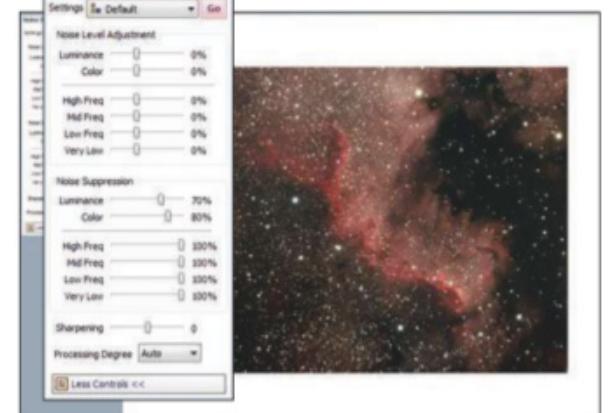
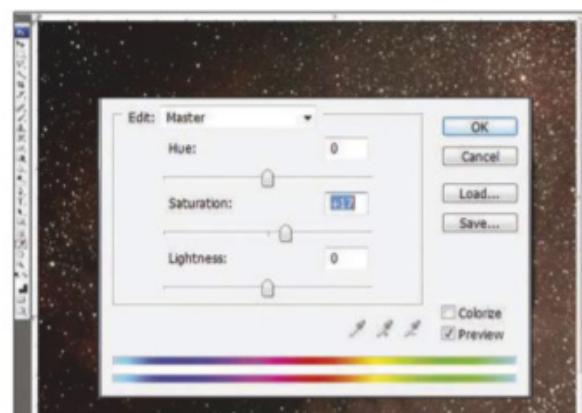
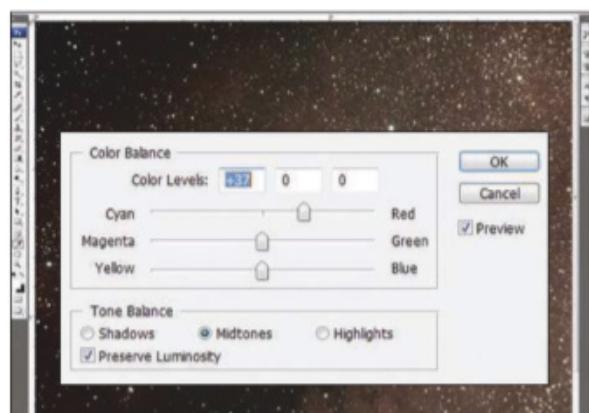
2 Tweak the shadows

Import the TIFF version of your image into either Photoshop or GIMP and select the levels tool. Select each colour channel in turn and slide the left-hand adjustment (shadows) to the right until it touches the start of the histogram to balance the colours across the frame.



3 Apply a gentle 'stretch'

Select the curves tool and choose the RGB channel (value in GIMP). Click on the diagonal line 3/4 of the way from the left side and drag it up to brighten the lighter areas. Click 1/4 of the way along the line and drag down to make an S-shaped curve and darken the background.



4 Colour correction

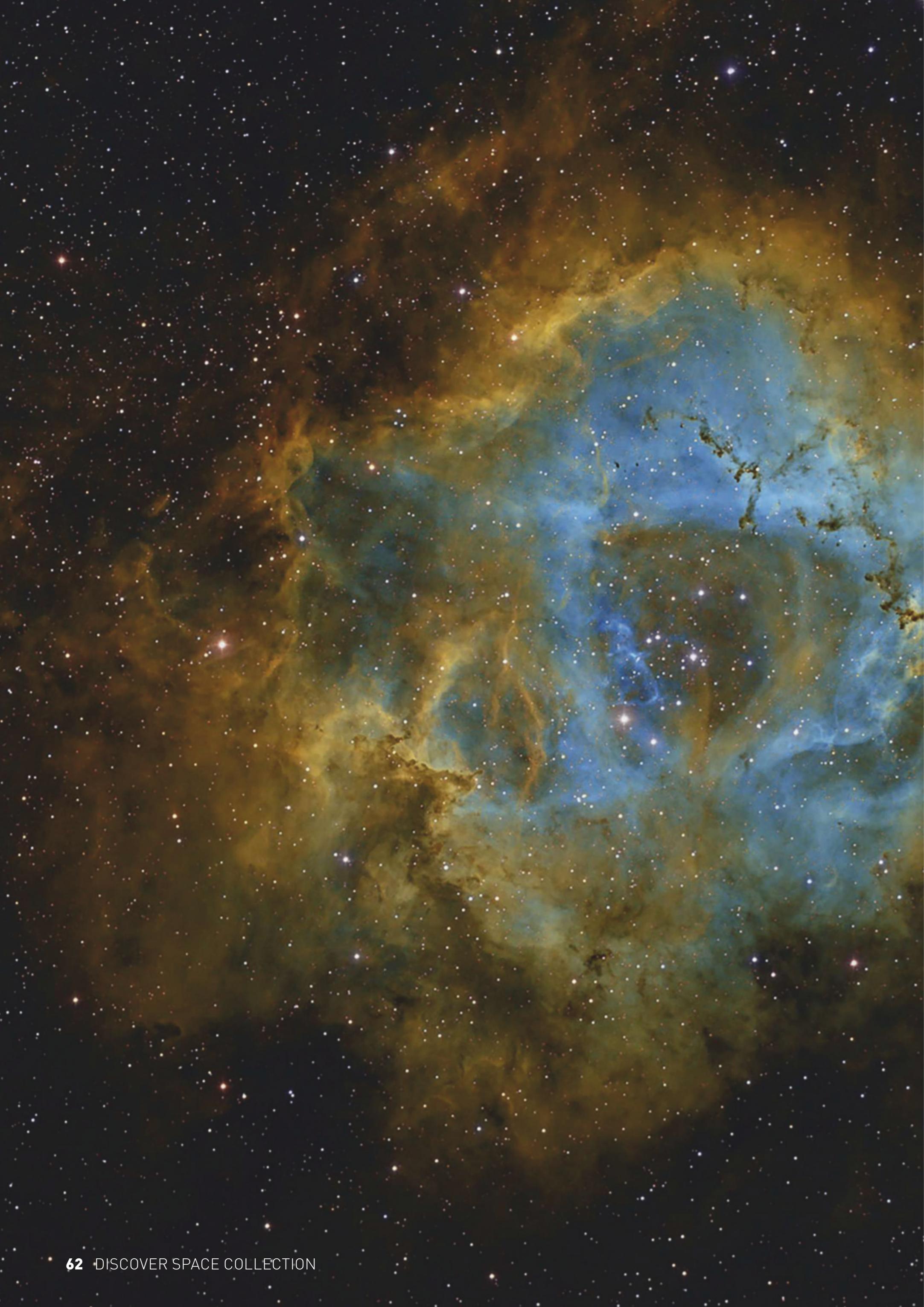
Your image should be looking more vibrant now but you may wish to enhance a particular colour. Select the colour balance tool and use the relevant slider to achieve the effect you want. These work in opposing pairs: cyan-red, magenta-green and yellow-blue.

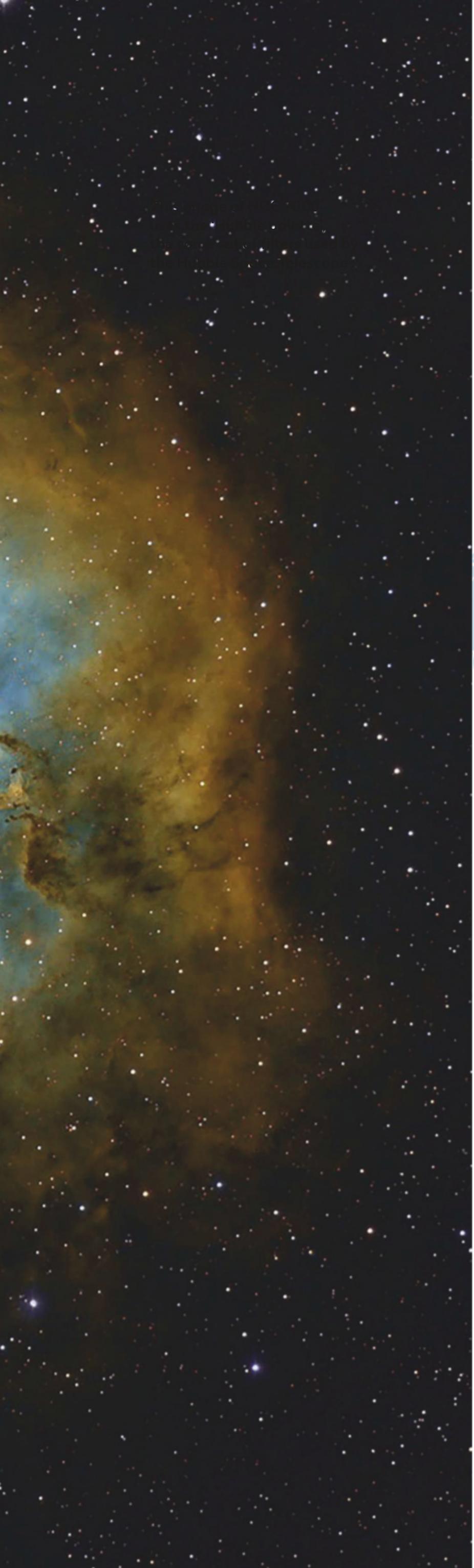
5 Saturation control

Curves can boost saturation levels, but if you want to alter the colour saturation in your image, select the saturation tool and adjust the middle slider a little to the right to increase saturation or to the left to decrease, then click OK. Make lots of small adjustments here.

6 Smoothing

Many images benefit from some careful smoothing. With the freeware Imagenomic Noiseware Community Edition, make a smoothed version of your image. Paste it on top of the original image and adjust the transparency until the original detail just shows through.





◀ This image of The Rosette Nebula uses the 'Hubble palette', the same set of filters used by the Hubble Space Telescope

THE DEEP SKY ADVANCED

Now we'll help you take your deep-sky imaging a step further. In the previous section we looked at the minimum equipment needed to produce deep-sky images, with the emphasis on DSLRs and one-shot colour CCD cameras. Wonderful images of deep-sky objects can be captured using these tools and for many imagers this is the only type of

camera they will ever need. But there are advantages to using a 'more advanced' setup with a mono camera and filters to produce your images, and we'll be concentrating on working with this kit here. We'll also be exploring the dark art of autoguiding, which enables longer exposures to give you deeper, smoother images and the ability to capture dimmer objects. ▶

WHAT YOU'LL LEARN

64 Equipment

Introducing the dark art of autoguiding and imaging with narrowband filters

66 Technique

How to take lengthy, drift-free exposures to capture faint celestial targets

68 Masterclass 1

Add a luminance channel to a stacked colour image to bring out extra fine detail in the North America Nebula

70 Masterclass 2

Use narrowband filters to produce an image of NGC 7000 in the classic Hubble palette

OUR EXPERT



Steve Richards is a seasoned deep-sky imager and *BBC Sky at Night Magazine's* Scope Doctor

EQUIPMENT

Correct tracking errors and take better images



A popular way of autoguiding is with a guidescope and camera alongside the imaging scope

Autoguiding is a very powerful technique, but it's seen as something of a 'dark art'. Many imagers are put off doing it for fear that it will be too much hassle to implement. It isn't a technique that works straight out of the box, so to speak, but the rewards for mastering it – well-shaped stars and deeper images thanks to longer exposures – make the effort worthwhile.

Autoguiding has one simple purpose: to detect any unwanted movement in a 'guide' star and to apply a correction to the mount to keep it pointing in exactly the right direction. Movement of the guide star is monitored with a guiding camera. If the software controlling the guiding camera notices that the guide

star has changed position, it must follow that the imaging camera and its telescope will also capture this unwanted movement, since both cameras are on the same mount. Any correction made by the guiding camera's software will, therefore, also correct tracking errors affecting the imaging camera. Modern software is able to detect these errors down to sub-pixel levels, making them very sensitive indeed.

The most popular method of autoguiding is to attach a second telescope and guiding camera either directly onto the imaging telescope (known as piggybacking) or next to it on a side-by-side mounting bar. This method makes it fairly simple to locate

a suitable guide star near to the object being imaged. Piggybacking the guiding scope on top of the imaging telescope is perhaps the easiest method of attachment, but this can result in increased leverage on the mount, as the centre of gravity moves further out. Many imagers prefer to use the side-by-side attachment arrangement, fitting additional mounting hardware, such as a second saddleplate, to bring the centre of gravity closer to the middle of the mount.

Guided by a star

An autoguiding session starts by choosing a suitable guide star and then calibrating the software to ensure that the mount corrections are applied in the right direction and with the correct amount of movement. This procedure is automated in software and involves moving the mount independently in its right ascension (RA) and declination (dec.) axes and noting how far, and in what direction, the star has moved for a given input. This calibration routine forms the basis for the software to calculate the type of correction the mount should make to counteract any movement of the guide star.

Once calibrated, the autoguiding system can be set running to counteract any unwanted movement of the guide star on the guide camera's sensor, thus ensuring that the imaging camera is also corrected for this movement. Having an autoguiding system makes it possible for routine exposures of five to 10 minutes to be taken, which means that fine detail can be captured without the risk of star trails appearing in the image.

Whereas a mount's Periodic Error Correction (PEC) will correct for the average periodic error of the mount's gearing system, autoguiding will correct not only these errors but also any other tracking errors caused by outside influences, such as weight shift and wind shear.

When using a second telescope for autoguiding, both the piggyback and side-by-side methods of attachment



◀ Off-axis guiders fit between camera and scope, and feature a pick-off prism, below

have something of an Achilles heel: small amounts of movement between the two scopes that are difficult to correct. This unwanted movement is called 'differential flexure' and can result in the imaging telescope moving independently

of the guide scope. So while the mount is correcting the errors seen in the guide scope, the imaging telescope is still not fully corrected.

To help solve this problem, a growing number of astrophotographers use an off-axis guider. These are fitted between the imaging camera and the telescope's focus tube, and use a small prism to pick off a sample of the view seen through the same telescope as the imaging camera.

Using the same telescope for both guiding and imaging avoids the risk of differential flexure and combats the problem of 'mirror flop' in Schmidt-Cassegrains. Unfortunately, though,

off-axis guiders are not without their own problems. It can be difficult to achieve simultaneous focus of both the imaging and guiding cameras, and the much-reduced field of view supplied by the prism, compared with that supplied by a second scope, can make locating suitable guide stars more difficult.

The common factor in either system is the guide camera itself. This is normally a fairly simple CCD camera that, as well as capturing the test-star images, also has built-in electronic switches. Connected with a cable to the mount's ST-4 guiding port, these adjust the mount's RA and dec. axes to correct any unwanted movement.

TECH TALK: LRGB and narrowband filters



The Wall, captured as an LRGB image

△ Mono CCD camera with LRGB filters

A mono CCD camera can produce naturally coloured images of a lot of deep-sky objects by using a mix of red, green and blue filters. Higher quality colour images use an extra component: the luminance channel. Our eyes detect fine detail in an image through brightness and contrast, rather than the colour components, which are simply 'painted' on top of this fine 'canvas'.

The luminance channel is the most important, so capture this data at the highest resolution. You don't need a specific filter, but an infrared filter is normally used to stop stars appearing bloated through light splatter.

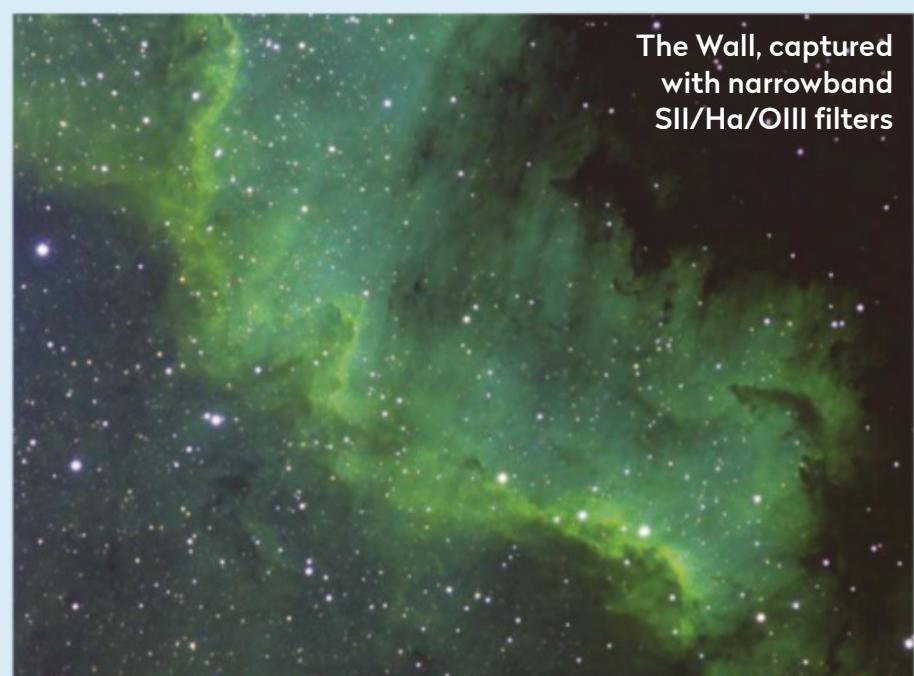
If you're short of time, you can capture the RGB data at a lower resolution than the luminance with little drop in quality. You can use this to your advantage by 'binning' the colour data 2x2 (merging four pixels into one). This lets you capture images in five minutes that have a similar signal-to-noise ratio to 'unbinned' images taken over 20 minutes, albeit at a lower resolution. Devote half your imaging time to the unbinned, luminance channel and half to the three binned, colour channels. As always, more subframes for each filter set will increase the signal-to-noise ratio. You need to resize the channels to match the unbinned luminance data before combining them to create an LRGB image.

▽ Mono CCD with narrowband filters

Narrowband filters only collect data from specific portions of the spectrum – useful for producing crisp, false-colour images of deep-sky objects with an emission component. Popular emission lines include hydrogen-alpha (H α), oxygen-III (OIII), sulphur-II (SII) and hydrogen-beta (H β). Such filters can produce detailed mono images, but by combining them in a similar way to RGB data, you can produce exquisitely detailed, false-colour images by mapping the narrowband images to the R, G and B channels.

'False colour' images do not necessarily produce the colours we're used to seeing; the emphasis is on clarity rather than colour fidelity. But you can produce reasonably realistic colours by combining filters in the correct wavelength order.

The H α emission line is in the middle of the band of wavelengths that a red filter lets through, while the OIII emission line is on the border between the wavelength bands passing through a green and blue filter. So by mapping your H α data to red and your OIII data to both green and blue channels, you can produce realistic colour images with just two narrowband filters. The H β emission line is well within the passband of a typical blue filter so by mapping H α to red, OIII to green and H β to blue, you can create quite natural and highly detailed colour images.



The Wall, captured with narrowband SII/Ha/OIII filters

TECHNIQUE

Use drift alignment to eliminate unwanted star trails

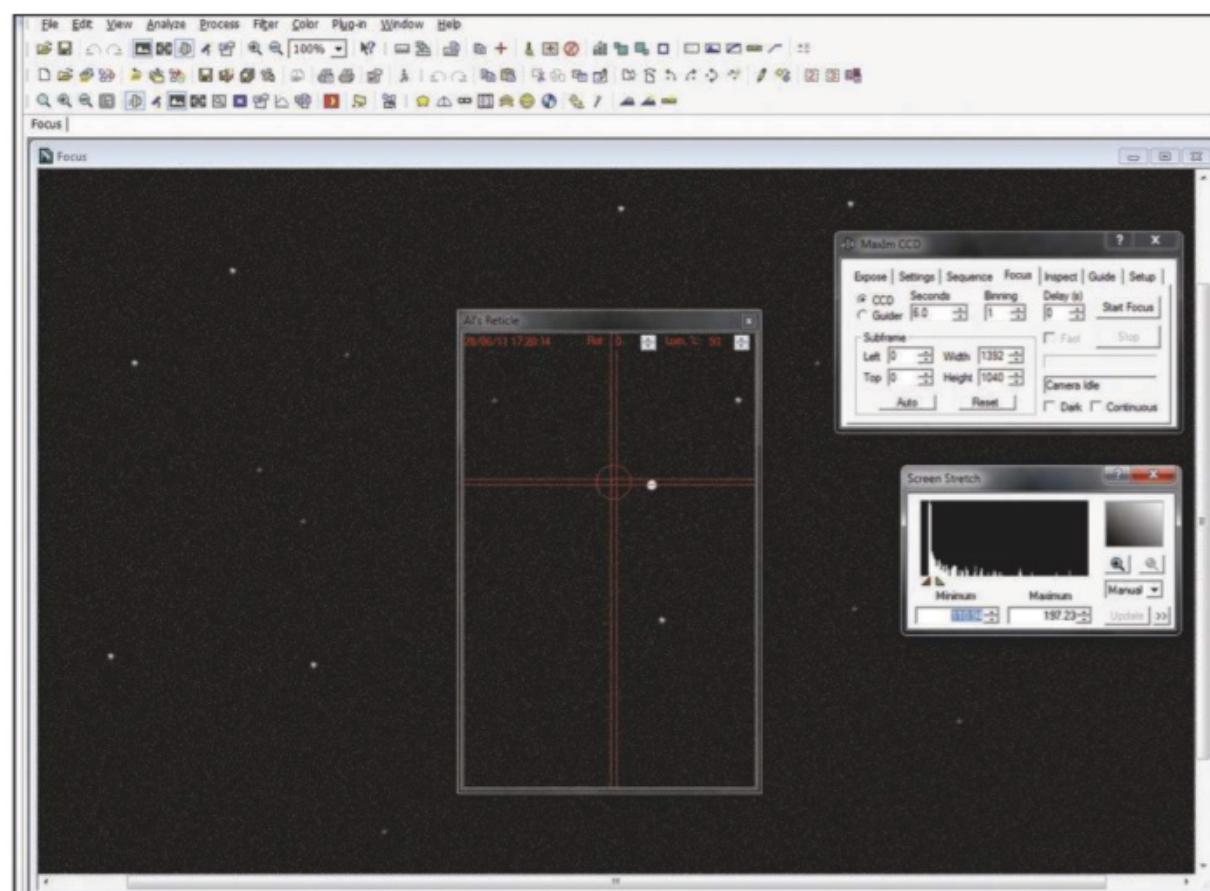
Accurate polar alignment is a very important preparatory step for deep-sky imaging. Indeed, the longer an exposure lasts, the more accurate the alignment needs to be. If your polar alignment is not sufficiently accurate, long exposures will start to show trailing in the stars towards the edge of the field of view, caused by field rotation. Using a mount's built-in polarscope is fine for shorter exposures of up to about 180 seconds, but it doesn't really cut the mustard when it comes to the longer exposures that you need for imaging deep-sky objects. You're far more likely to get a better shot using drift alignment – a much more accurate method of alignment that should be used whenever possible.

Drifting away

Drift alignment relies on a process of detecting the movement, or drift, of two chosen test stars caused by a mount's misalignment with Earth's axis. One test star is high near the celestial equator and the other is low to the east or west, whichever has the clearest horizon. If your polar alignment isn't absolutely spot-on, a target star will appear to drift upwards or downwards in declination over time, so correcting this drift for stars at these two locations – at right angles to one another in the sky – will align the mount accurately with the north celestial pole.

Whereas polar alignment with a polarscope doesn't require the mount to be absolutely level, a level mount will help with drift alignment by cancelling any interaction between the movement of the azimuth and altitude planes. To assist you with detecting this drift, you can download an excellent freeware program called Al's Reticle, written by Australian amateur astronomer Alan Sheehan. Al's Reticle overlays a moveable and rotatable double crosshair on top of any other program you're running, which you can use to watch for drift in your chosen star.

To drift align, start with your mount reasonably polar aligned using your



▲ Al's Reticle is free software that uses crosshairs to check for drift in your chosen star



▲ Drift alignment involves making small adjustments to azimuth and altitude bolts

polarscope. Install your imaging camera so that the widest side of the image frame is in line with the right ascension (RA) axis. Then point your telescope at a bright star high on the celestial equator and start taking a continuous series of six-second exposures of it.

With the mount tracking the night sky at sidereal rate, focus carefully on the star, then place it on the horizontal crosshair in Al's Reticle. The most accurate way of detecting any drift is to position the crosshair so that it bisects the star.

Watch the star for several minutes, checking for any drift up or down. Adjust the mount's azimuth bolts to move the star back onto the crosshair and correct for any drift you detect. Any drift in this plane indicates that the mount is pointing too far to the east or west of the north celestial pole. Only make small adjustments, slackening off one bolt and tightening the opposing bolt. As you get closer to correct alignment, the amount of adjustment required will gradually reduce. Continue making smaller and smaller adjustments until no up or down drift is detected for four or five minutes.

Now point your telescope towards your eastern or western horizon, whichever affords you the best view of the stars, and choose another bright star. Again, place the test star on the horizontal crosshair so that it's bisected by the line and start watching for up or down drift. This time, correct any drift with the altitude bolts. Use the same process as before to make adjustments until no drift is detected for four or five minutes. On this second star, drift errors indicate that the mount is pointing either above or below the north celestial pole.

PRO POINTER: Setting up an autoguider

Guidescope and camera

There are two ways to set up a guidescope and camera combination – they can either be piggybacked on top of your imaging telescope's tube rings, or attached alongside it on a dual mounting bar.

The guiding camera should then be attached to the focuser using an extension tube in place of the diagonal, which should be removed as this can be a source of flexure.



▲ Attach the ST-4 cable from the guide camera to the port on your mount

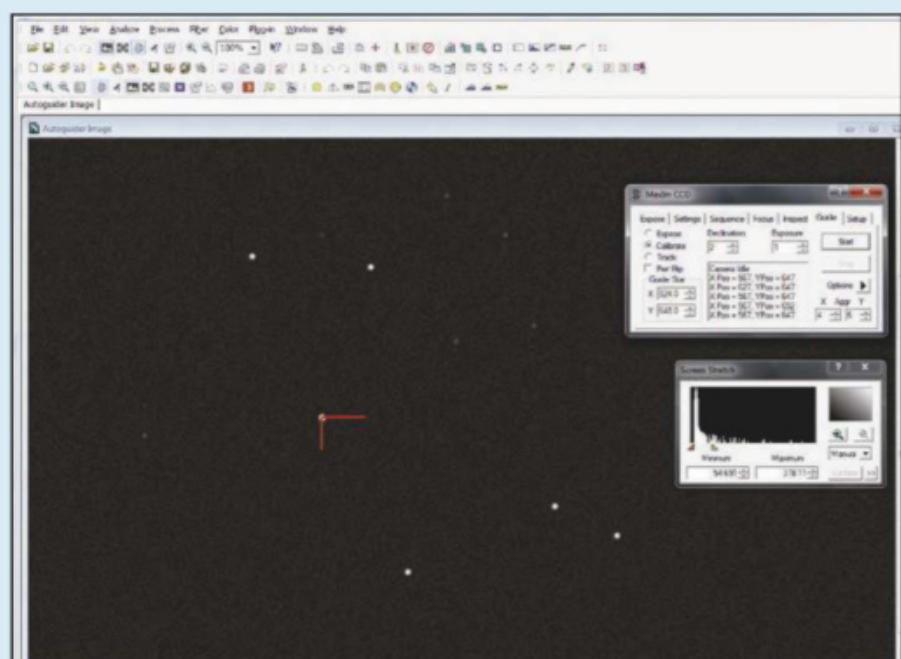
The mount should be carefully balanced in right ascension (RA) and declination (dec.) to ensure that no undue strain is placed on the mount's motor drives. Unbalance the mount, as we explained on page 57, once you have slewed to your chosen subject.

Connect the guide camera to your computer's USB port, then plug the ST-4 guiding cable between the camera and the ST-4 port on your mount. Now carry out a one-star alignment: choose a bright star near the target you want to image and, once aligned, slew to the object.

Run the guiding calibration routine using autoguiding software such as PHD or MaxIm DL. This calibration routine traces an L-shaped figure on your preview screen

showing test movements in positive and negative RA and dec. directions, centred on your guide star. The software then 'learns' how far the guide star moves for a control

output sent from the guide camera to the mount, so it can make accurate mount corrections. Once calibrated, set the autoguiding function running and start imaging.



▲ A calibration program uses an L-shaped icon to 'learn' the movements of the guide star as the mount moves

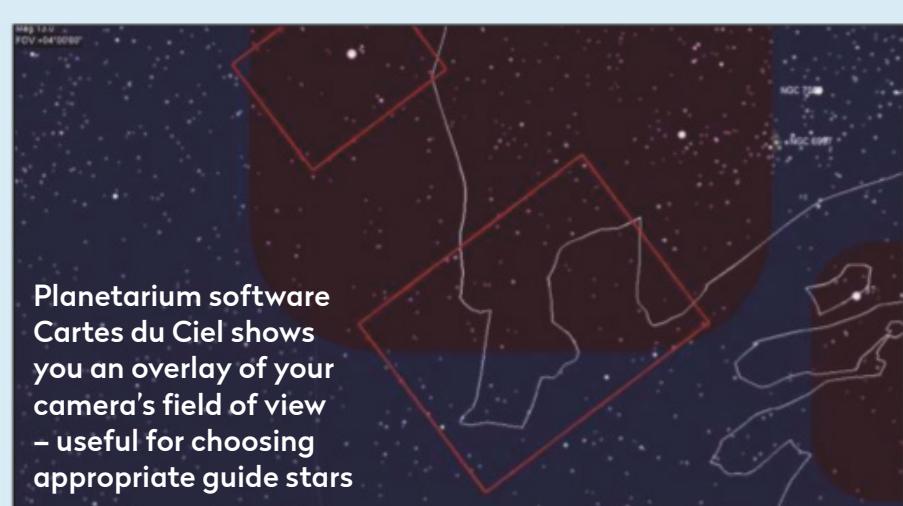
Off-axis guider

Off-axis guiders are a popular alternative to a guidescope but have some limitations. Inserted between the camera and the eyepiece holder, the extra space they take up can make it impossible to achieve focus with a camera, especially with Newtonian reflectors that already have limited back focus.



▲ Off-axis guiders fit between camera and scope, and feature a pick-off prism, below

The imaging and guiding cameras must be in focus at the same time, so spacers are normally needed to achieve this. The best approach is to set the off-axis guider up in daylight and focus the imaging camera on a distant object. The guiding camera can then also be focused on the same object in readiness for the imaging session. This only needs to be done once;



the spacers can be left in situ for later imaging sessions. If you're using a filter wheel, insert this between the imaging camera and the off-axis guider, leaving an unfiltered light path for the guide camera.

It can be difficult to find a suitable guide star in the small field of view using an off-axis guider, but with planetarium software such as Cartes du Ciel, you can choose suitable guide stars in advance of your imaging

session. Cartes du Ciel's reticle feature lets you produce a rectangular overlay matching your camera's field of view for framing purposes, it also shows a secondary offset rectangle representing your guide camera's field of view and position. Using this you can calculate the angle of rotation you need from the guide camera so that it captures a suitable guide star, while maintaining your chosen image frame with your imaging camera.

MASTERCLASS 1

Image the Wall, the brightest part of the North America Nebula, using LRGB filters



STEVE RICHARDS X 8

For the masterclass in advanced deep-sky-object imaging, we're going to show you how to produce a full-colour image using LRGB filters and a mono CCD camera.

A mono CCD camera is a versatile piece of equipment: it lets you capture data using a wide range of filters to achieve different results. Add to this the ability to take long exposures with

reduced electronic noise, thanks to built-in Peltier cooling, and you can see why a mono CCD is such a powerful tool.

Your choice of filter size will be dictated by the size of your sensor, as well as your pocket. Although it is possible to remove the camera and replace each filter in turn, doing so is really not recommended! Without a filter wheel, it's a tortuous task to make sure that every part of your imaging setup goes back in place correctly so that the individual groups of images line up with one another.

Although a computer-controlled electronic filter wheel is very nice, a manual wheel removes a level of complexity from the system and is pretty much guaranteed to have repeatability of filter placement each time. Despite ranges of good-quality filters being designed to be parfocal, wise astrophotographers will always check focus when it comes to swapping to the next filter, so unless you have completely automated focus as well, the appeal of an electronic filter wheel diminishes further. However, electronic wheels do

FOCAL REDUCERS AND FIELD FLATTENERS

Many deep-sky objects, particularly nebulae, are quite large, so a large sensor and a short focal length telescope are required in order to fit them into the field of view. But large sensors tend to accentuate a problem inherent in most telescopes – that of field curvature.

Most telescopes produce a curved focal plane yet a CCD's sensor is flat, so if accurate focus is achieved with stars at the centre of the field of view, those towards the field edges will be out of focus and will take on a stretched appearance. This effect is made worse by using 'fast' optics, yet fast telescopes with their small focal ratios of around f/5 and f/4 are desirable for capturing the dim light from deep-sky objects.

Luckily, there's an elegant solution to this: use a combined focal reducer and field flattener. These special double-element optics are installed between the CCD camera and the focuser, where they

reduce the apparent focal length (thus reducing the focal ratio), but also correct the field curvature thanks to the way their optics are configured. The result is far sharper stars at the field edges.



▲ A combined focal reducer and field flattener keeps field edges sharp

have one great advantage over their manual siblings: once the filters are installed they're protected from dust and light as there is no wheel edge projecting from the casing for you to manually revolve.

Plan ahead

It's useful to plan an imaging run in advance to make sure that you make the best of your available time. In LRGB imaging, your luminance data is the most important as this decides the deepness and detail of your image, but how you capture your RGB data can have a great effect on the final image too.

What you're trying to achieve in RGB imaging is a finished picture that replicates the colours seen by the human eye through matching the spectral

sensitivity of the CCD's sensor to your eyesight, which is most sensitive to green light. A CCD sensor normally has its highest sensitivity in red light, which is great for imaging emission nebulae. However, the use of filters and a naturally occurring effect known as atmospheric extinction, which reduces the brightness of night-sky objects, will further skew the sensitivity of the sensor to red, green and blue.

If you were to take equal length exposures for each of your three colour filters, your images could end up with a colour cast to them (which is why DSLR cameras have an automatic 'white balance' feature built in). To compensate for this skewed sensitivity, it's necessary to either use different exposure times for each colour, or adjust an image's

colour balance after imaging, using post processing software.

Earth's atmosphere naturally scatters blue light more than the other colours, so if you can reduce the amount of atmosphere it has to travel through, your blue data will be crisper and less noisy. Aim to capture your blue data when your chosen object is at its highest in the sky.

Just as important as your image data are your calibration frames. Bias frames are not dependent on the filter in use but your flat frames certainly are, especially if you're hoping to remove any dust in your images. Although dark frames are not directly dependent on the filter in use, bear in mind that if you have used different exposure lengths for each filter, you'll need dark frames of a matching exposure length for each filter too.

STEP BY STEP: Create an image of The Wall using LRGB captures



1 Luminance

With the luminance (infrared) filter selected, good focus and the autoguider running, start imaging. It pays to capture luminance first so that if the clouds roll in during the session, you'll have something worthwhile for your trouble. Take at least 10 480-second exposures.



2 Red channel

Once you've got the luminance data capture under your belt you'll have a pretty good idea of what your image is going to look like, so change the filter to red and carefully re-check the focus, adjusting it if necessary. Take six 240-second exposures, binned 2x2.



3 Blue channel

With NGC 7000 high in the sky, change to your blue filter and check focus. If you're using an ED doublet refractor and parfocal filters, it's likely the focus will match the red filter, and with a triplet refractor it should be bang on. Take six 360-second exposures, binned 2x2.



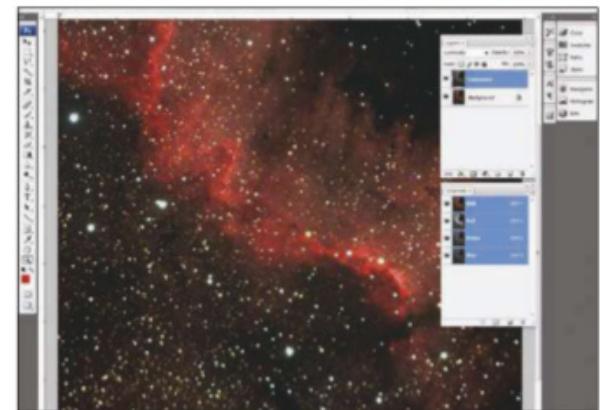
4 Green channel

Finally, image with the green filter. If the cloud rolls in before you capture this set, there's a way of producing a full-colour image from what you've already shot (see p92). Check focus again because if any colour will be out, it'll be this one. Take six 300-second exposures, binned 2x2.



5 Calibration

If you have an electroluminescent panel or light box, capture your flat frames after you've taken each set of filtered images (or the following day without disturbing the focus). The bias and dark frames can be taken inside at any time. Calibrate each set of filtered images.



6 Stack, align and combine

Stack the images into four masters, double the size of the colour masters and align with the luminance. Produce an RGB file the same size as the luminance master and populate each channel with its colour. Paste the luminance channel on top and set the blend mode to Luminance.

MASTERCLASS 2

Create a false-colour image in the Hubble palette

We've shown you how to make natural-colour images using a mono CCD camera and broadband red, green and blue filters, but narrowband filters can also be used to produce colour images with a twist. Although narrowband data can be combined in much the same way as RGB data to produce images with fine detail, these images will show false colours. RGB data is assembled in order of decreasing wavelength, with red (740nm-625nm), green (565-520nm) and blue (500-435nm) assembled in that order.

If you follow the same ordering procedure using the popular emission lines of Ha (656nm), OIII (501 and 496nm) and SII (673 and 672nm), you can see that SII is 'redder' than Ha. So SII would be mapped to the red channel, Ha would be mapped to the green channel and OIII would in turn be mapped to the blue channel, producing an SII/Ha/OIII image.

With a typical emission object like the Wall in NGC 7000, this combination of filters will collect some great data but you may be surprised by the overall colour, which will appear very green. This is because the predominant emissions

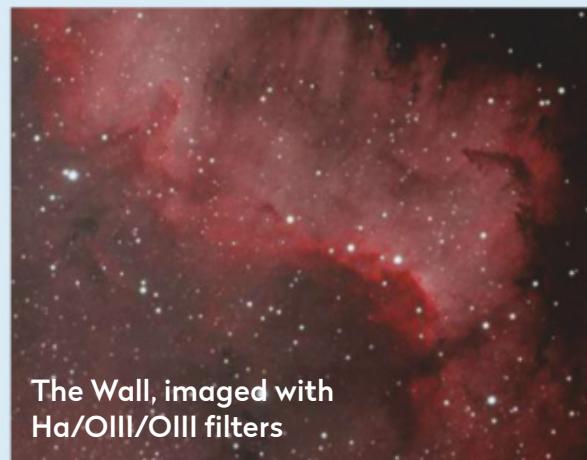
STEVE RICHARDS X9



PRO POINTER: Making natural images with narrowband filters

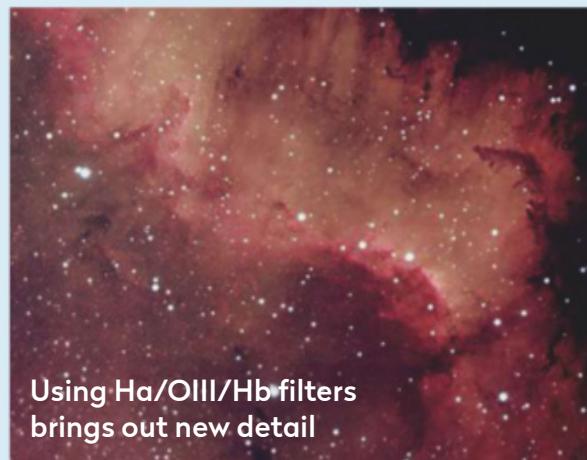
Narrowband filters aren't limited to depicting objects in unusual ways. Not only can they be used to produce natural colour images, but also there are sometimes advantages to using them over broadband filters.

The OIII emission line's place in the spectrum is right between green and blue, so it could be used to produce either a green or a blue channel. Even better, the same data can be used to produce both the green and blue channels in the same image. This has the advantage of reducing image-capture time if the conditions are likely to deteriorate, which is why we recommend that you record it immediately after capturing your Ha data.



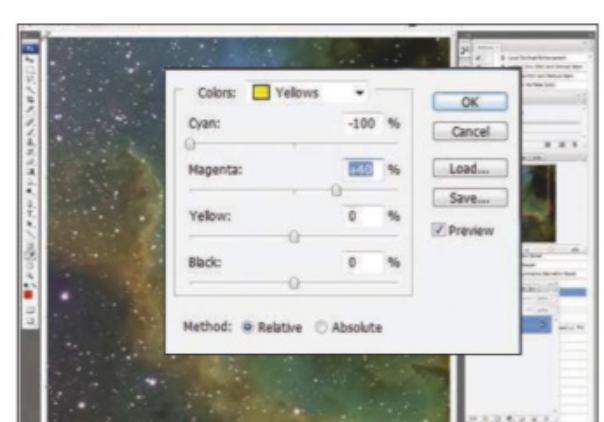
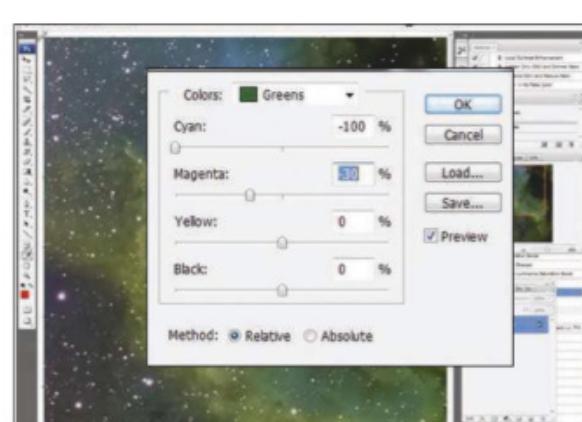
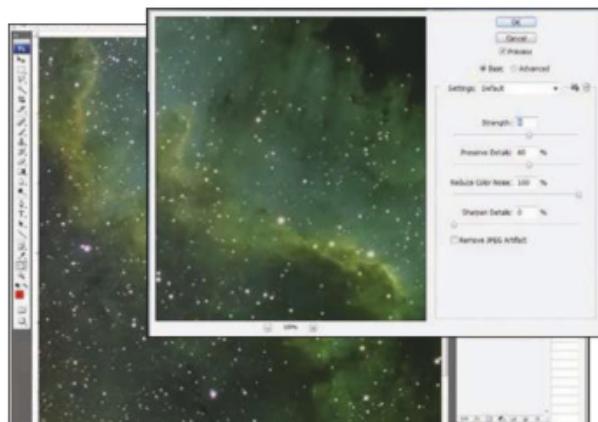
Simply map your Ha data to red and your OIII data to both green and blue, and you'll be pleasantly surprised at how natural-looking your images become.

Some emission objects also respond well to hydrogen-beta (Hb) data, which



is more 'blue' than OIII and so can be mapped to the blue channel. So although Hb data appears in the same regions as Ha, it can certainly bring something extra to the mix, even though it's much fainter than Ha.

STEP BY STEP: Recreate the classic gold and turquoise of Hubble



1 Combine and reduce star hues

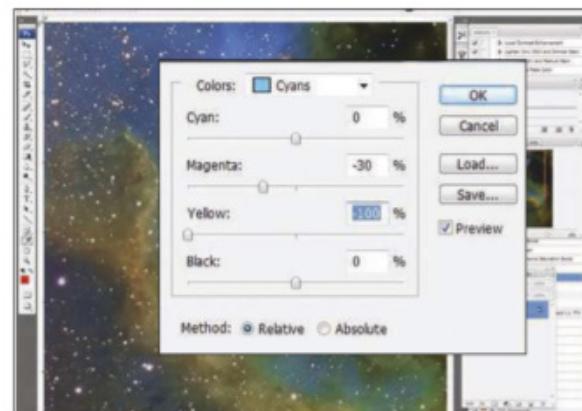
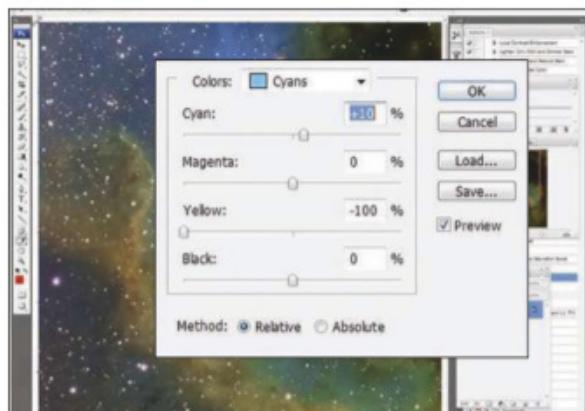
With your masters aligned and combined, you'll see a lot of green. But take note of the magenta stars too: these must be dealt with first. Select **Filter > Noise > Reduce noise > Reduce colour noise**. Set this to 100 per cent, which will remove the unwanted star colour.

2 Turn greens yellow

The first step in transforming your image to the palette's gold and turquoise is to convert the green colours to warmer ones. Select **Image > Adjustments > Selective colour**, then **Greens** from the menu. Reduce the cyan level to -100 per cent and the magenta to -30 per cent.

3 Add golds

The next step is to enhance the fairly light yellow detail further by making it more golden. Select **Image > Adjustments > Selective colour** and then **Yellows** from the menu. Reduce the cyan level to -100 per cent and increase the magenta to +40 per cent.



4 Tweak the cyans

Now we turn to the cyan-to-turquoise transformation. First, shift the cyan components towards blue. Select **Image > Adjustments > Selective colour**, then **Cyans** from the menu. Increase the cyan level to +10 per cent and reduce the yellow level to -100 per cent.

5 Tweak cyans further

The second part of the cyan-to-turquoise transformation enhances the cyan by reducing the magenta and the yellow. Select **Image > Adjustments > Selective colour** then **Cyans** again. This time, decrease the magenta level to -30 per cent and the yellow level to -100 per cent.

6 Colour saturation and curves

Boost colour saturation (the same way you did in step 5 of Masterclass 2 on page 61). Adjust the tonal range of your new image with the curves dialogue box: the aim here is to produce a gentle 'S' curve to darken the background and enhance colour and contrast.

from this object are in the H α band, which has been mapped to the green channel. This colour appearance is certainly false – just as that famous Hubble image of the Pillars of Creation shows false colours – but it will show a huge amount of fine detail. As we shall see though, this false colour image can be further processed to reveal even more detail.

Framing the Wall

You'll almost certainly have to take these image sets over two or three nights. Start by carefully adjusting the orientation of your imaging camera to frame the Wall at its best, perhaps using the framing technique suggested on page 55. Ensure that you have achieved a really good

focus, set autoguiding running then begin your imaging run by capturing the H α data first, as this is the predominant component.

Because the H α component dominates the object in this way, it makes sense to get this under your belt first. That way, if the conditions deteriorate over the course of your imaging session, you'll at least have a detailed mono image to take away with you. Take at least 20 500-second exposures and then move onto the OIII filter, re-checking your focus before you start the next run. Now take at least 20, 500-second exposures again. We're leaving the SII data until last as interesting results can be achieved using just your H α and OIII data (see 'Pro Pointer', opposite for more on this).

Once you've captured your H α and OIII data, take a set of SII-filtered images comprising 20 800-second exposures, but remember to re-check that all-important focus first. Now calibrate and stack each of the three sets of filtered data into three masters and align them using the H α master as your base image. Save each as a 16-bit TIFF file.

You're now ready to import the three master files into Photoshop and combine them. Open all three files and select the SII image. Copy the SII data to your clipboard. Now select **File > New** and set the colour mode to RGB. Select the **Channels** tab, click on the red channel, then paste (to map the SII channel to red). Copy and paste the H α and OIII into the green and blue channels respectively.

TAKE YOUR ASTRO IMAGING TO THE NEXT LEVEL

Steve Richards explores several ways you can go from capturing good astro images to great ones

CEDIC TEAM/CHRISTOPH KALTSEIS/CCDGUIDE.COM

Astrophotographers constantly strive to improve their images by whatever means they can – it's in their nature to do so! These improvements normally come about in small steps made possible by using longer exposures, improved focus, more precise tracking, more sensitive cameras, exotic filters and better optics. Each small change adds to the whole, so that better contrast is captured in dim galaxies and nebulae, sharper images with greater colour saturation are produced, star shapes are improved and

hitherto unseen features are revealed. So what do you need to do if you really want to take it up a notch? Here we detail some of the kit you can use to help take your astro imaging to the next level. ▶

OUR EXPERT



Steve Richards is a seasoned deep-sky imager and *BBC Sky at Night Magazine's* Scope Doctor





To capture images as
impressive as this shot of
the Pleiades, you'll need
the right equipment

GRAB AN AUTOGUIDER



◀ Left: Bresser Guiding Kit AR90/500; below: a typical off-axis guider

One of the most obvious ways of improving your deep-sky images is to take longer exposures to capture more detail. The trouble is, doing so puts greater demands on your mount, because it has to accurately track your target for longer periods of time. But with an autoguider you can give your mount a helping hand.

Autoguiding uses a second camera to take a continuous series of short exposures of a 'guide star' near to the object being imaged. The position of the guide star on the camera's sensor is analysed, and if the star starts to move in any direction the autoguider issues a command to the mount instructing it to follow the star's movement. This second camera can either be connected to a second telescope



▲ Autoguiding can deliver sharper images: on the left is an unguided five-minute exposure of Vega in Lyra; right, a five-minute guided shot

attached to the mount (known as a guidescope), or to the imaging telescope via an off-axis guider. Off-axis guiders use a prism to pick off a small sample of light from the edge of the light cone that falls on the main imaging camera's sensor. This sample is then diverted to the guide camera for analysis.

Whichever type you use, if the corrections from the autoguider mean the guide star is accurately tracked, the imaging camera and telescope will also track your target accurately as they're attached to the same mount.

Guide cameras, such as the Starlight Xpress Lodestar X2 Autoguider, can be controlled by a laptop and guiding software or operate on their own. Stand-alone guiders, such as the Sky-Watcher SynGuider, are also available.

FINE FOCUS WITH A BAHTINOV MASK

Deep-sky objects are relatively dim and so are very difficult to focus on. But using a simple device called a Bahtinov mask can simplify the task enormously.

To use a Bahtinov mask, simply place it over the front of your imaging telescope and then point the instrument your at a bright star near to the object that you're intending to image. The numerous cut-outs in the Bahtinov mask produce a very specific set of diffraction spikes, in the same way that the spider vanes of a Newtonian reflector cause a simple cross to appear on images of bright stars. But instead of a simple cross, the mask produces an X-shaped cross bisected by a horizontal line. Adjusting the telescope's focus while taking a continuous series of short exposures



◀ A Bahtinov mask makes use of diffraction, which occurs when a wave encounters a slit

of the bright star causes the cross to move in relation to the horizontal line – when the line exactly bisects the cross,

▲ Minor adjustments alter the symmetry of diffraction spikes a Bahtinov mask creates

you have achieved perfect focus. If the star is in focus, any other deep-sky object will be too.

MAX OUT YOUR MOUNT

It's not just your camera that's packed with technology

Without doubt, the most important piece of an astro imager's kit is the mount. The mount supports the weight of the rest of your imaging equipment and moves it with precision so that it tracks the apparent movement of the sky, which is crucial for crisp astro images.

It's important that the mount's payload capacity is not exceeded – the best tracking results are achieved with the mount operating at well under its rated capacity. If you're close to your mount's payload capacity, then you probably need to upgrade to a larger mount.

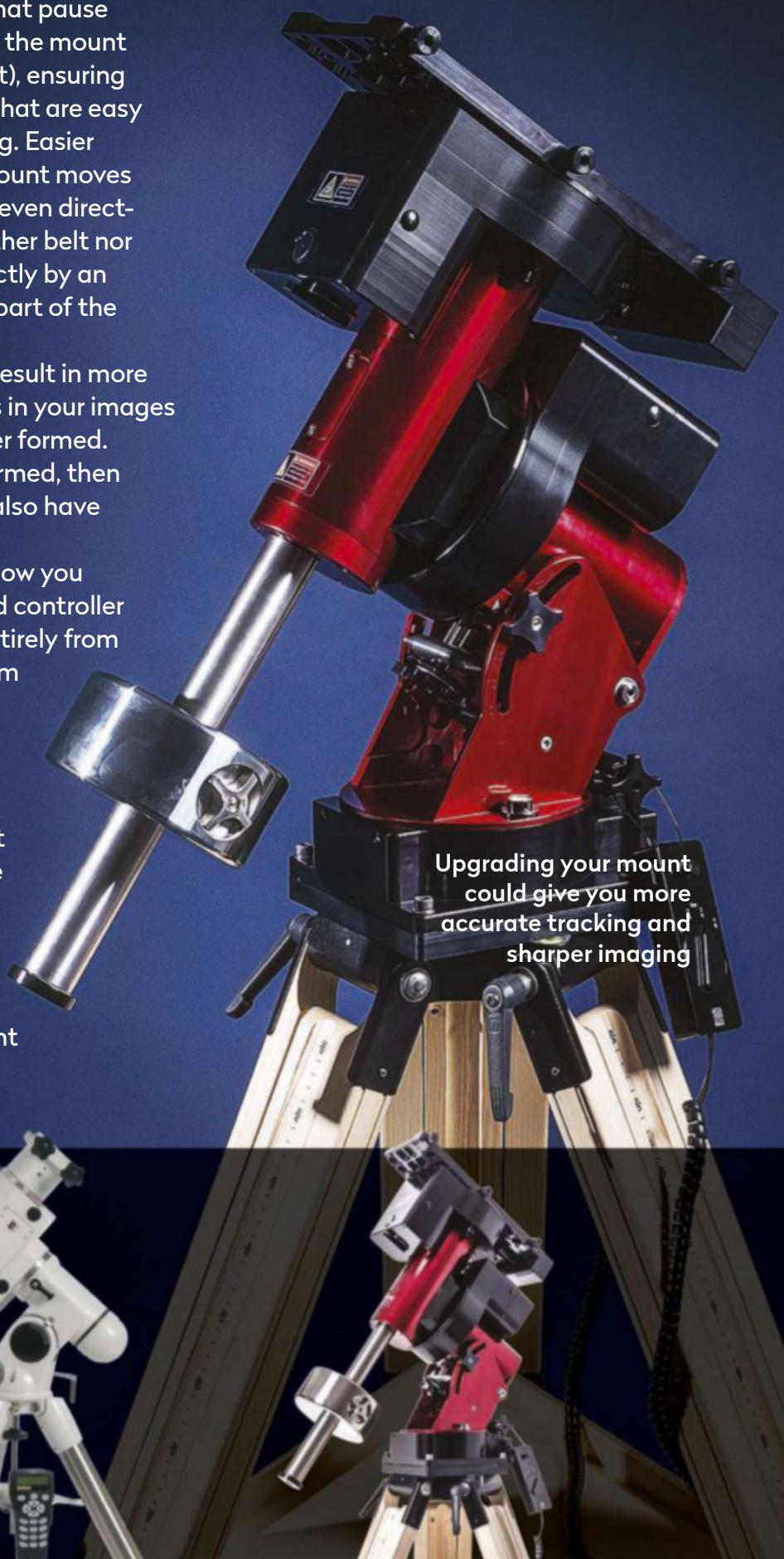
But it's not all about capacity. An upgraded mount could also introduce some valuable new features, such as periodic error correction (PEC). PEC is a process in which the movements required to correct a mount's periodic tracking errors are recorded over a single rotation of the tracking drive's gears, then played back to automatically correct the errors in subsequent rotations.

By upgrading your mount you could take advantage of new drive technologies, for instance drive belts that eliminate any manufacturing defects in the gear meshing of conventional geared mounts. You could also consider friction drives, which have no gears or belts but rely on the contact of a driven spindle against a metal disc. This removes all

backlash from the drive (that pause you sometimes get before the mount responds to a control input), ensuring very small periodic errors that are easy to correct with autoguiding. Easier autoguiding means the mount moves more smoothly. There are even direct-drive mounts that use neither belt nor friction but are driven directly by an electric motor that forms part of the right ascension axis.

All these upgrades can result in more accurate tracking, so stars in your images become sharper and better formed. And if the stars are well formed, then the deep-sky objects will also have greater fidelity.

Upgrading could also allow you to dispense with your hand controller and operate the mount entirely from your computer. Planetarium programs, with their graphical user interfaces, make choosing and acquiring new targets simple. This type of mount operation is so much more enjoyable than having to plough through the menus on the hand controller to get to the object catalogues or mount functions that you want.



UPGRADE OPTIONS



MESU 200

Price: £5,399.00

Payload: 100kg

Supplier: www.modernastronomy.com

The unusual look of the PC-controlled Mesu 200 is a triumph of design over art. The Mesu 200 uses a friction drive that results in a backlash-free mount capable of handling a huge payload.

SKY-WATCHER NEQ6 PRO

Price: £1,179

Payload: 18kg

Supplier: www.opticalvision.co.uk

This is the workhorse mount for many advanced imagers, as it provides unbeatable payload capacity for its price, responds very well to autoguiding and can be fully laptop-controlled.



PARAMOUNT MYT

Price: £6,550

Payload: 23kg

Supplier: www.iankingimaging.com

The Paramount MYT combines portability with a high level of accuracy thanks to automated sky modelling and 'Pro-Track' software that eliminates errors from refraction and flexure.

UP YOUR SENSITIVITY

Larger sensors and better cooling improves your images

The sensors in CCD cameras have a grid of electronic photoreceptors. Photons falling on these receptors are converted into electronic charges, which are then read by the camera. More photons means more charges, meaning greater light levels. Sensors with more receptors are able to record the varying light levels that fall on them and record these for processing into an image.

DSLR cameras use large sensors (typically APS-C type, 22.2 x 14.8mm in size) and because of economies of scale in their production, they're great value for money, hence they're a popular choice for deep-sky imaging. But the sensors in DSLR cameras are very sensitive to infrared wavelengths of light, so manufacturers fit an infrared blocking filter to tame this, as it's rarely wanted by photographers. Unfortunately, these filters cut out some of the light wavelengths that are of interest to deep-sky imagers.

Another problem with DSLRs is that all sensors generate heat in operation, and this heat produces 'noise' in the images. This noise isn't really noticeable in the short exposures (typically 1/60th of a second to 1/2,000th of a second) that DSLR cameras are designed for, but it



▲ CCD cameras like this Atik model come with built-in cooling

becomes intrusive in the long exposures (five minutes or more) required for deep-sky imaging.

Astronomical CCD cameras address these issues. They're supplied without an infrared blocking filter, so they're capable of recording a much wider range of wavelengths. Infrared is still unwanted for most deep-sky imaging purposes,

however, so an external filter tailored for astronomy is used instead. Astronomical CCD cameras also have a device called a Peltier cooler installed behind the sensor. This is a thermoelectric heat exchanger that typically cools the sensor down to 25-30°C below the ambient temperature, reducing sensor noise and making this type of camera ideal for long exposures.

UPGRADE OPTIONS



ATIK HORIZON

Price: £1,549.00 (mono) £1,219.00 (colour)
Pixels: 4,644 x 3,506 (17.6 x 13.3mm)
Supplier: www.widescreen-centre.co.uk

The Atik Horizon houses a cooled, 16MP sensor with low read noise and fast read speeds. It makes a great option if you're looking to upgrade from a DSLR and comes in monochrome or one-shot-colour versions.



STARLIGHT XPRESS TRIUS-SX25C

Price: £2,525
Pixels: 3,024 x 2,016 (23.4 x 15.6mm)
Supplier: www.widescreen-centre.co.uk

Matching the size of a typical DSLR camera sensor, this one-shot colour CCD camera is perfect for wide-field imaging and can be brought down to 35°C below ambient temperature with its cooler.



QSI 683 WSG-8

Price: £3,510
Pixels: 3,326 x 2,507 (36 x 24.7mm)
Supplier: www.iankingimaging.com

The QSI 683 WSG-8 combines a large monochrome sensor with an eight-slot filter wheel and a built-in off-axis guider port, producing an elegant and precise, all-in-one solution for deep-sky imaging.

INVEST IN NARROWBAND FILTERS

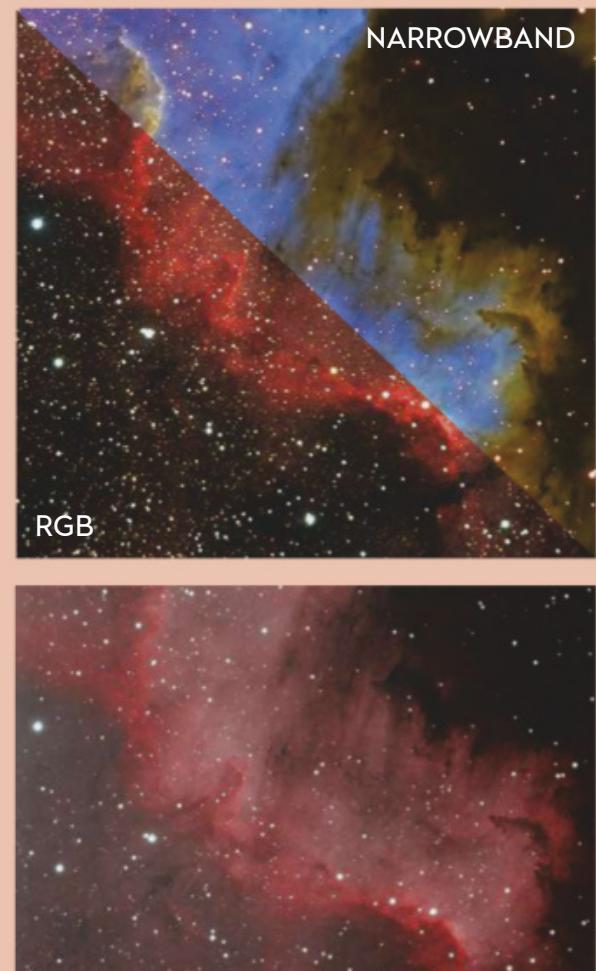
There are two ways of capturing colour images with modern cameras. The first is to use a one-shot-colour CCD or DSLR to capture a full-colour image in a single shot. The other involves a monochrome CCD camera, but this requires a different approach. With a monochrome CCD you capture three sets of images through red, green and blue (RGB) coloured filters, then combine them afterwards into an RGB colour image using processing software. The main advantage of a mono CCD camera is that you can also image through a range of other types of filters to capture all sorts of extra detail.

Standard RGB filters are known as 'broadband' filters but there are also various 'narrowband' filters available, the most popular being hydrogen-alpha (H α), oxygen III (OIII) and sulphur II (SII). These filters let through a narrow band of wavelengths corresponding to the light emitted by objects such as star-forming nebulae and planetary nebulae. By combining images taken

- A small region of NGC 7000, imaged in narrowband (top) and RGB (bottom)

through narrowband filters, you can produce beautiful false-colour images containing exquisite levels of detail. Another side-effect of narrowband filters is that they filter out wavelengths associated with most artificial lighting, enabling you to capture high-quality, light pollution-free data.

The most common narrowband filter combination involves processing the final image so that the data captured through the SII filter goes into the red channel of an image, Ha to the green and OIII to the blue; this process of 'mapping' the data to the colour channels produces the final full (false) colour image. Another mapping that works well requires only two sets of narrowband image data: Ha and OIII. By mapping Ha to the red channel and OIII to both the green and blue channels, very natural-looking colour images can be produced.



▲ H α /OIII mapping can be used to create images with natural-looking colours

OPTIMISE YOUR OPTICS

Good quality optics are needed if you want to avoid chromatic aberration, where coloured fringes appear around bright objects (the result of different wavelengths of light being focused at different distances from the objective lens of refractors). Other issues include field curvature in refractors and coma in reflectors, both of which cause stars to appear as pinched, shaped stars towards the edges of the field. Refractors use special low-dispersing glasses to focus different wavelengths of light to the same point, reducing chromatic aberration. But the best results are achieved with a multi-element apochromatic (apo) lens, such as the Astro-Physics Starfire EDF, William Optics Series 115 F7 ED Triplet and Sky-Watcher 100ED. Field curvature can be fixed with a lens, such as a Petzval lens, which fits between the camera and the telescope. Using a Petzval lens arrangement, such as the FSQ-106ED or the PrimaLuce Lab & Field Flattener, have field flattening and the effect of using a parabolic mirror to flatten the field of view in reflectors, but it can be easily resolved with a lens.



▲ The PrimaLuce Lab Airy APO 65F is one example of a high-quality apochromatic refractor.

MODIFY YOUR DSLR

Although DSLR cameras can capture great deep-sky images, the lack of red sensitivity caused by their infrared filters will eventually become a limiting factor. Fear not, these cameras can be modified for astrophotography.

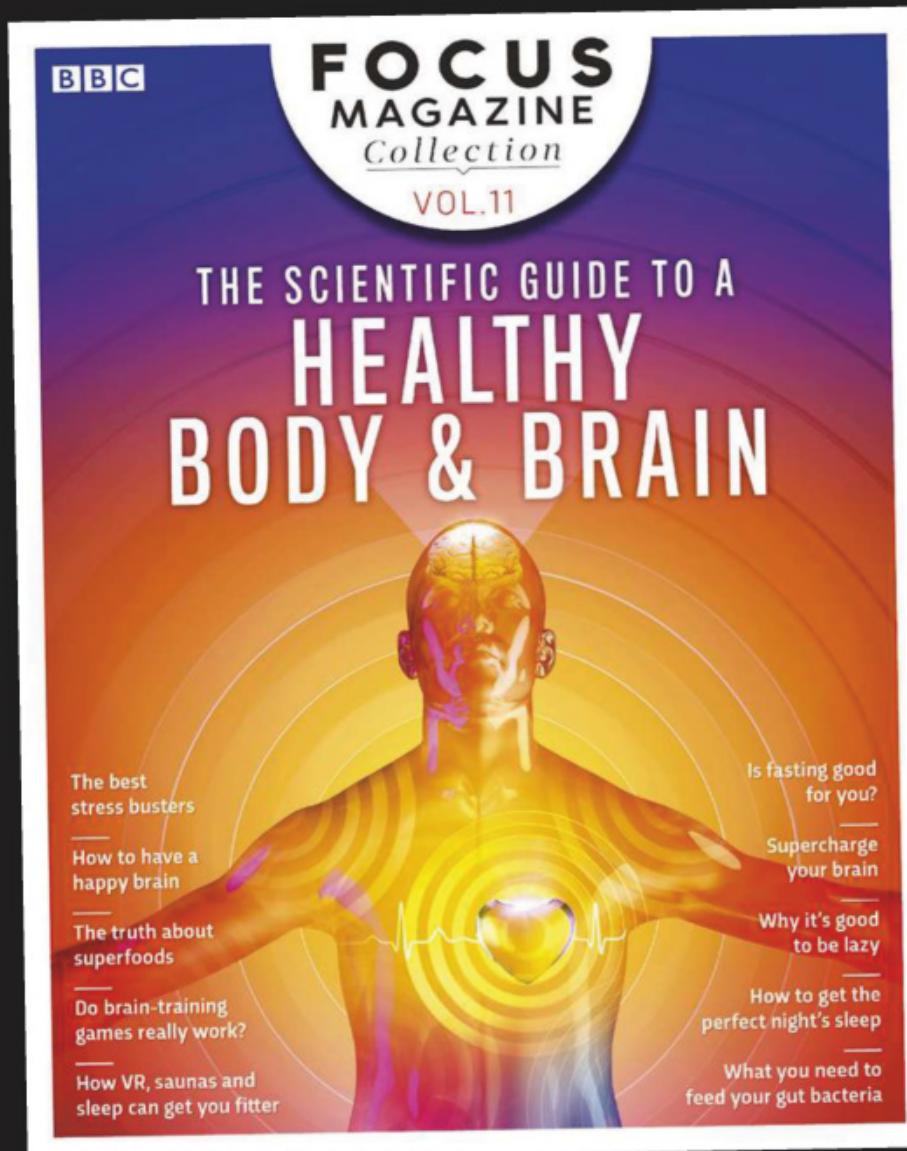
Common modifications include removing the infrared filter completely or replacing it with a filter that passes the hydrogen-alpha wavelength but cuts the unwanted infrared wavelengths. You can make either modification yourself, but there are risks involved as a complete strip-down of the camera is required, invalidating any warranty. Various online resources explain the process in detail if you enjoy a challenge and accept the potential risks, which include destroying the camera.

Canon and Nikon used to produce suitably modified cameras – the 60Da (APS-C) and D810A (full frame) respectively – but these have been discontinued. However, several companies will carry out conversion work on other DSLR cameras, including Astronomiser in the UK (who work exclusively with Canon cameras), Baader Planetarium in Germany, Astro Hutech in the US, PrimaLuce Lab in Italy and JTW in the Netherlands, who will also modify Nikon and Sony DSLRs.

- It is possible to get newer Canon EOS DSLRs such as the 70D modified for astrophotography



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IMAGE PROCESSING



A very important part of modern digital astrophotography is image processing. In fact, it can come as quite a shock to realise that the amount of time spent processing and tweaking the most successful astrophotos completely outweighs the time spent capturing them.

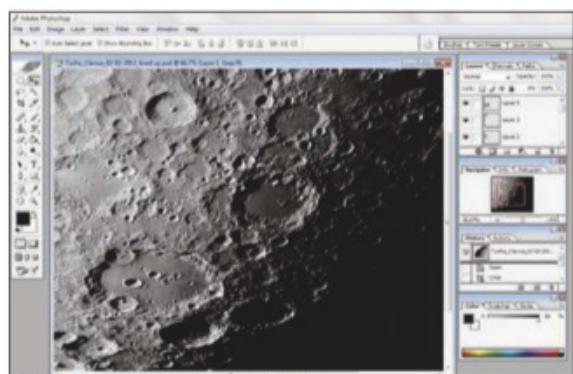
The range of processing functions available in image-editing software is quite bewildering and knowing which ones to use to achieve the results you want can be quite daunting. But don't worry – this is what we'll be covering in this section of *The Complete Guide to Astrophotography*.

In this image processing section, you'll find clear, useful explanations of which processes to use when – such as how to rid your night-sky images of the orange cast caused by light pollution, as well as step-by-step walkthroughs on essential processing routines, including how to create a full-colour image from monochrome shots.

Our tutorials are split by Solar System and deep-sky objects, and then again by basic and advanced techniques; below you'll find details of the programs we use throughout. As ever, the best advice is to experiment and to always keep your original files somewhere safe in case you need to backtrack.

ESSENTIAL SOFTWARE

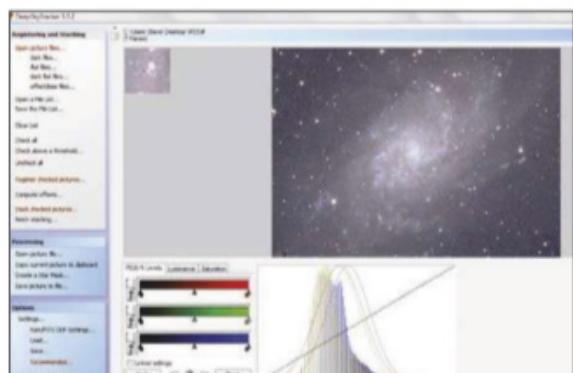
Layer-based photoediting programs



Layer-based photoediting programs, such as GIMP (freeware) or Photoshop will allow you to manipulate the content of an image. The layers allow you to make fine adjustments to certain aspects of

an image before combining the layers together into the final image. Software like this is great for final image tweaks.

Deep-sky processing programs

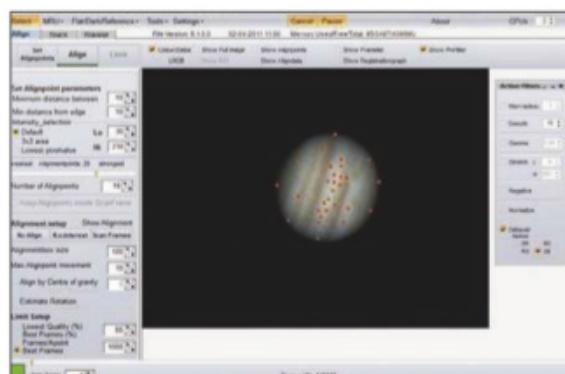


Specialist programs, such as AstroArt, ImagesPlus, Astro Pixels Processor, Star Tools, as well as freeware DeepSky Stacker and Iris, can help you get the best out of long-exposure deep-sky images.

ISTOCK

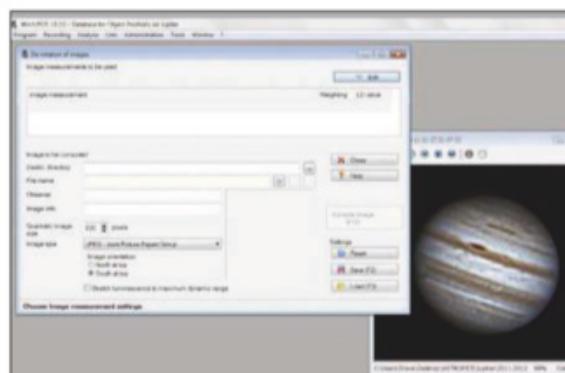
PixInsight is a powerful image-processing system, removing the need for other programs such as photoediting software.

Registration and stacking software



The process of registration and stacking is relevant to both Solar System and deep-sky imaging. It's used to reduce image noise by averaging numerous still shots. Freeware applications such as RegiStax and AutoStakkert are ideal for processing the multitude of images produced by high frame rate planetary cameras.

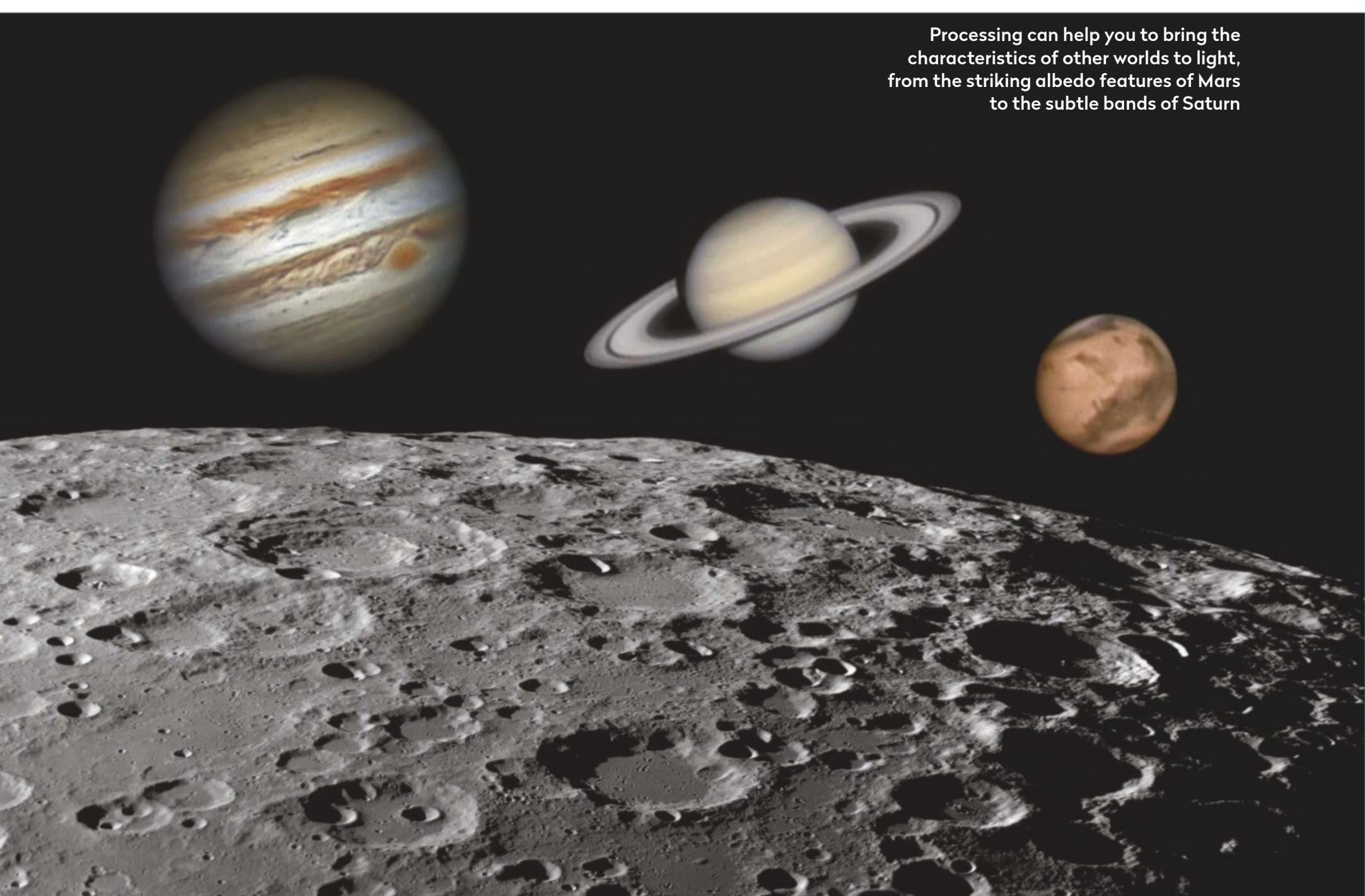
Specialist Solar System applications



There are many processing gems available. For example WinJupos (freeware) can derotate images of fast-rotating planets such as Mars and Jupiter. And PIPP (freeware) pre-processes planetary images ready for optimised registration and stacking. It's also great at producing animated sequences.

SOLAR SYSTEM OBJECTS BASIC TECHNIQUES

Processing can help you to bring the characteristics of other worlds to light, from the striking albedo features of Mars to the subtle bands of Saturn



To get you started in image processing we'll be looking at how to handle Solar System objects – the Sun, the Moon and the brighter planets. After going through a basic image building method we'll look at two important adjustment tools: levels and curves. Both allow you to alter specific tonal regions of your shots, which is useful for extracting detail from deep shadow or for pulling back bright

exposed regions. Levels is the simpler of two, with only three adjustment points, while curves offers complete freedom of adjustment. Mastering both is vital.

We'll also cover the tricky issue of planetary colour and introduce some simple techniques to help get filtered imaging colours right. Finally, we'll discuss some of the related techniques that can be used to enhance planetary detail. Some of these will be familiar, while

others will be a little more obscure, offering tremendous control over sharpening and tones in an image.

OUR EXPERT



Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

WHAT YOU'LL LEARN

81 Image building for beginners

Create colour images from filtered greyscale shots in six simple steps

82 Using levels and curves

Adjust the tones in your astro images and bring out previously unseen levels of detail

84 Colour handling

Balance the colours of your planetary images so that those seen in your captures match those seen in reality

86 Enhancing detail

How and what to blur, sharpen and blend to make your images pop with colour and clarity

IMAGE BUILDING

Create colour images from your greyscale shots



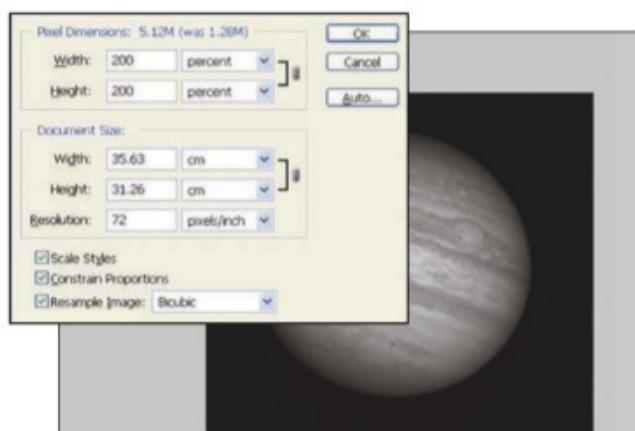
The best full-colour planetary images are achieved using a high frame rate monochrome camera fitted with swappable red (R), green (G) and blue (B) imaging filters. But in order to get to a final colour image, we need to perform a bit of construction work.

High frame rate cameras record movie sequences for each filter as AVI files, and these initially need to be processed with a registration and stacking application such as RegiStax or AutoStakkert. Programs like these will select

the best individual frames from an AVI movie file and stack them on top of each other. At the end of this process you get a sharper, brighter, more detailed image for each of the RGB filters, which you can then use to build your final image.

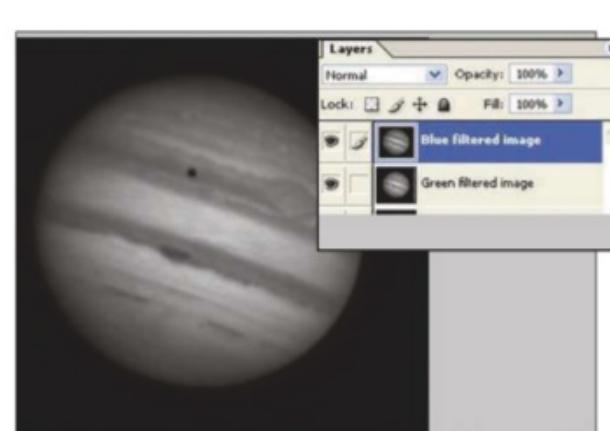
We're going to pick up from this point, where you have your three R-, G- and B-filtered greyscale images to hand. The guide below will help you transfer these into the colour channels of a blank RGB image to make one full-colour RGB photo.

STEP BY STEP: Combine your registered and stacked RGB images



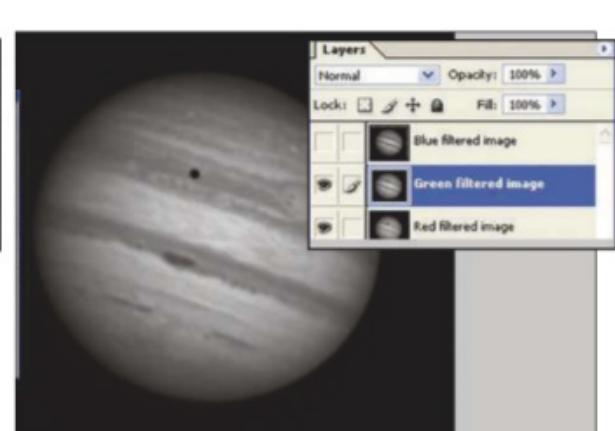
1 Red is your master

Open the red (R) image and resize it to 200 per cent to make alignment easier. This will be your master alignment image so save it under a new filename to reflect this.



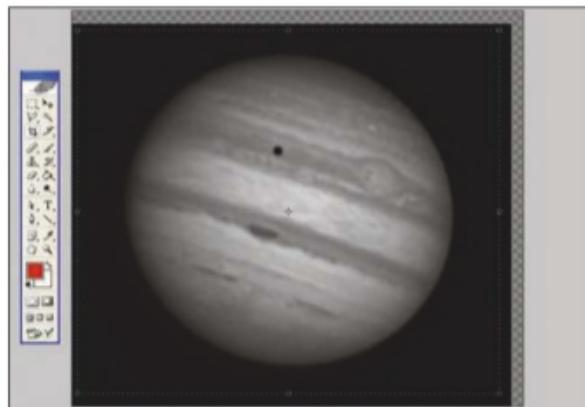
2 Green, then blue

Open the green (G) image and resize to 200 per cent, then select all and copy. Paste the G image into the R image from step 1 as a new layer. Repeat with the blue (B) image.



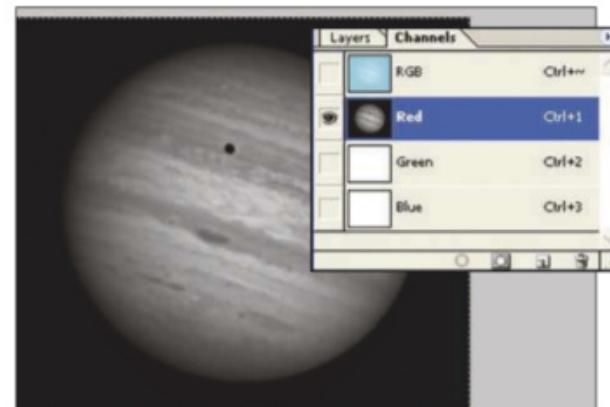
3 Nudge to align

Hide the B layer, then nudge the G layer so that it aligns with the R image – toggle the G layer's visibility to check its position. When aligned, repeat the process with the B layer.



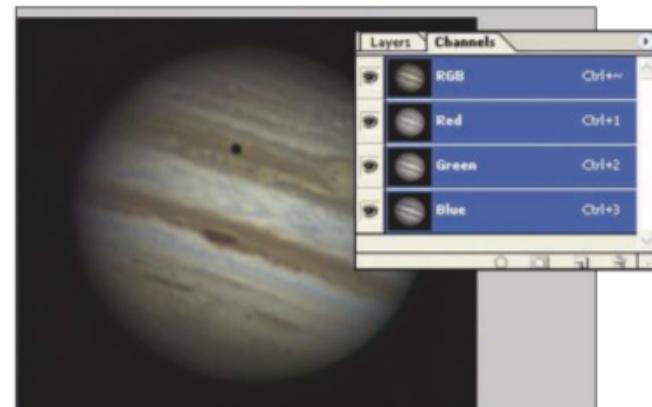
4 Crop the edges

Nudging the layers may reveal gaps around the edges of the G or B layers – use the crop tool to redefine the border of the image and remove them.



5 From layers to channels

Create a blank RGB image of the same size as the cropped image from step 4. Copy the R layer from step 4 into the blank image's R colour channel.



6 Complete the picture

Repeat step 5 for the G and B layers, copying the contents of each into the corresponding channels of the new RGB image. Save the full-colour RGB image.

USING LEVELS AND CURVES

How to adjust the range of tones in your astro images

The levels and curves adjustment tools let you target shadows, highlights and mid-tones in an image. Both have similar functionality, but the levels tool is simpler and easier to use than the curves tool. For the best quality, work with 16-bit rather than 8-bit images, if your software allows.

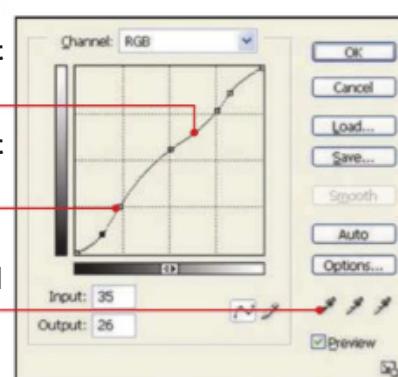
Levels shows a histogram of the number of pixels for each tone in the image and restricts you to just three sliders that alter the black, white and mid-points for an image. The black point defines a threshold pixel value below which all pixels are regarded as pure black; the white point defines the threshold above which all pixels will be regarded as pure white. The mid-point defines the

CURVES

Adjustment line

Adjustment points

Ink dropper sample tool



LEVELS

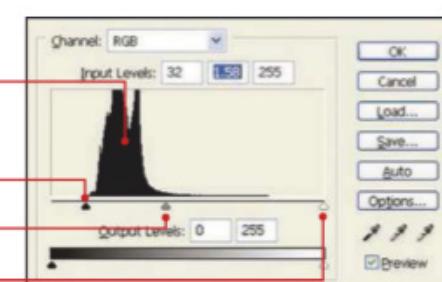
Histogram

Sliders:

Black

Mid

White



► The palettes for levels (above) and curves (left) allow you to alter the shadows, highlights and midtones in your images

mid-value between black and white, altering the intermediate tones to fit your redefined range.

The curves tool gives far more control, allowing you to redefine as many tonal points as you wish, but sometimes the

levels tool is perfectly adequate to get the best out of an image. When you need to artificially stretch the shadow regions of an image while keeping the rest more or less as it looked originally, however, the curves tool really comes into its own.

PLANETS



▲ Increase contrast, improve limb regions and control highlights in planetary images

Levels and curves can be used to enhance planetary images, increasing their contrast, dealing with indistinct limb regions and controlling the highlight that sometimes appears in the centre of a planet's disc.

The levels tool's histogram will ideally show a sharp peak close to the graph's left axis with a gentle rising 'hill' spreading horizontally across the rest of the graph. If the hill is bunched up towards the black point, the image is underexposed. If it's bunched towards the white point, then it's overexposed.

The sharp black-point peak represents the dark sky surrounding the planet. If

it's not up against the left edge of the graph, use the black-point's dropper tool and click it on the sky to make it black.

Move the white point so that it almost touches the rise of the histogram, but don't burn out the centre of the planet's disc. Then move the mid-point slider to adjust the overall appearance to taste.

The curves tool offers more choices, but take care to not upset the image's overall balance. Start by adding new points at quarter intervals along the adjustment line. Additional points at the 1/8 and 7/8 positions are useful for targeting shadows and highlights respectively.

THE MOON



▲ Improve definition in lunar shots by pulling out subtle shades

The levels and curves tools can pull out subtle shadow detail or recover information in over-bright regions. If your image contains dark sky around the Moon, select the black-point ink dropper and click it on the sky. This tells your software to define the sky as black. If there's no sky visible, adjust the black-point slider so it sits to the left of the histogram's foot. Don't make the shadows inside craters pure black as they'll look too severe; they should be a dark grey.

The histogram shows the number of pixels (vertical axis) in each tone

(horizontal). Black is on the left, white to the right. Setting the white point to represent the brightest highlight rarely works well, so here we'd recommend leaving the white point slider alone.

The curves tool is great for dealing with shadow and highlight regions. Start by creating points along the adjustment line at quarter intervals. Add additional points at the 1/8 and 7/8 positions to pull out deep shadow detail or to reduce over-bright highlights. Once adjusted, you may need to nudge the other points to restore the overall tonal balance of the shot.

THE SUN: Full-disc, white-light filter



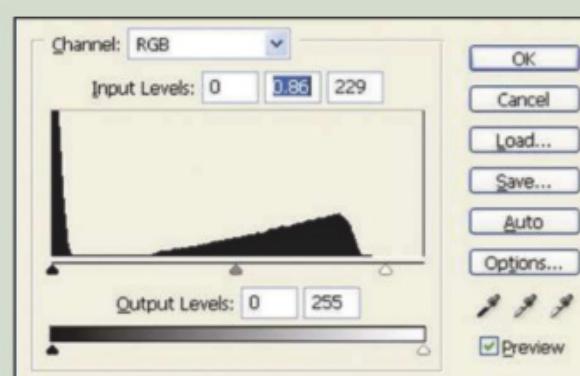
▲ Full-solar-disc images look great when contrasted with an entirely black sky

The white-light Sun doesn't show extremes of tone like the Moon. Instead, the tonal variation is much smoother, being brightest in the centre of the disc and darkest, at the edge. The sky surrounding the Sun should be pure black for the best effect.

The levels tool is ideal for adjusting full-disc images. Start by setting the black point with the black-point ink dropper

sample tool, clicking it on the surrounding sky. Adjust the white-point slider so that it sits just to the right of the main histogram. Move the mid-point slider, so that the centre of the image looks bright but not pure white. It should retain some tonal detail.

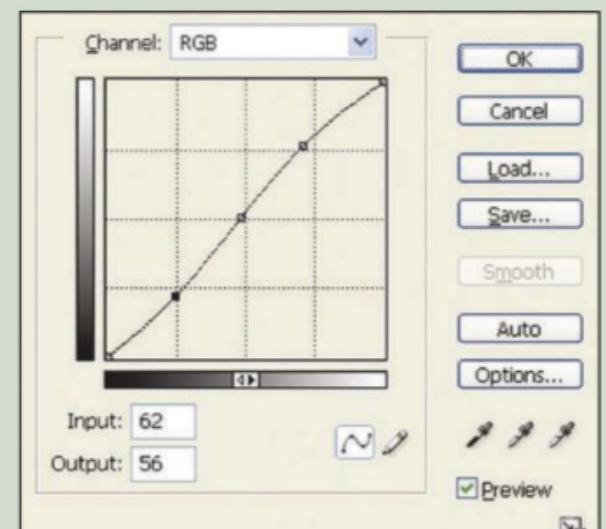
With curves, the simplest technique for full-disc shots is to place a point at each quarter position along the adjustment curve. A subtle S-shaped curve can work wonders here, and is achieved by keeping the central point fixed while nudging the lower one to the right and the upper one



▲ Levels: the white-point slider should be beyond the histogram to retain detail

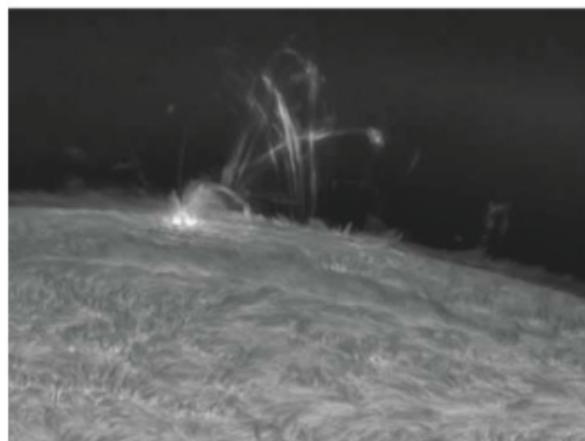
to the left. Don't make the edge of the Sun too dark and avoid burning out the centre of the disc. Once done, you might need to nudge the central point to restore balance to the image.

If done properly, a small S-curve adjustment can help to emphasise subtle edge detail such as bright faculae. A faster change of tone at the edge, moving to a slow brightening in the middle, can help show the Sun's sphere.



▲ Curves: place a point at each quarter position and create an S-shaped curve

THE SUN: Solar limb, hydrogen-alpha filter



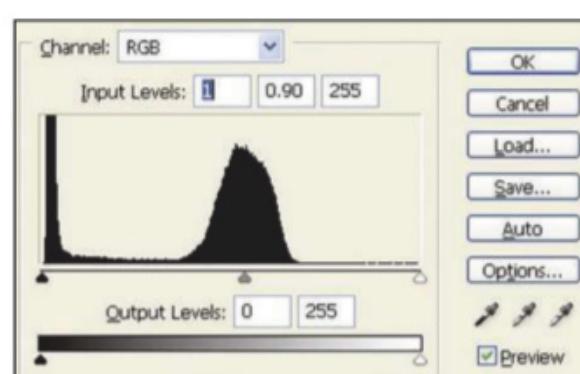
▲ Levels helps you retain detail in the solar surface and reveal hidden prominences

Unlike the white-light filtered Sun, our star appears highly detailed when imaged with a hydrogen-alpha filter. But the real challenge comes with the edge of the hydrogen-alpha Sun, as you have both surface detail and prominences to deal with.

If you set your camera to capture the surface detail so that it appears close to, but not quite, fully saturated – that is, the image doesn't quite contain any pure white – a levels adjustment may reveal prominences that are hidden in the background. When you look at the

image's histogram in levels, you'll typically see two peaks. The peak close to the black point represents the surrounding sky (mostly black or dark grey pixels) but it may also include prominence detail. The other peak represents the surface detail and will be between the middle and left edge of the graph.

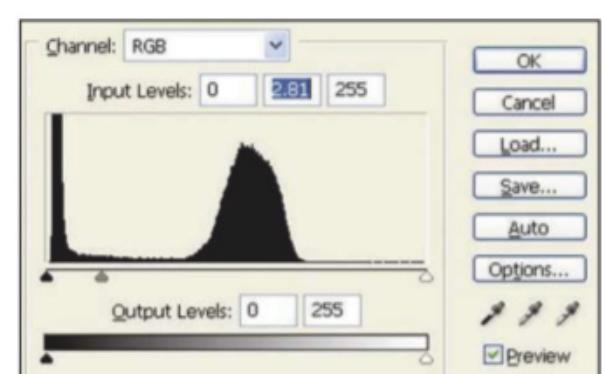
Duplicate the image and, on the copy, drag the mid-point slider right over to the left-hand (dark) peak – this will reveal any prominence detail. The other image will show surface detail, so with this, drag the mid-point slider so that it's roughly central below the main peak. You can



▲ For a hydrogen-alpha solar-disc image, drag the mid-point under the main peak

tweak this position to your own taste, but avoid too much contrast as the edge will become too dark and look unnatural.

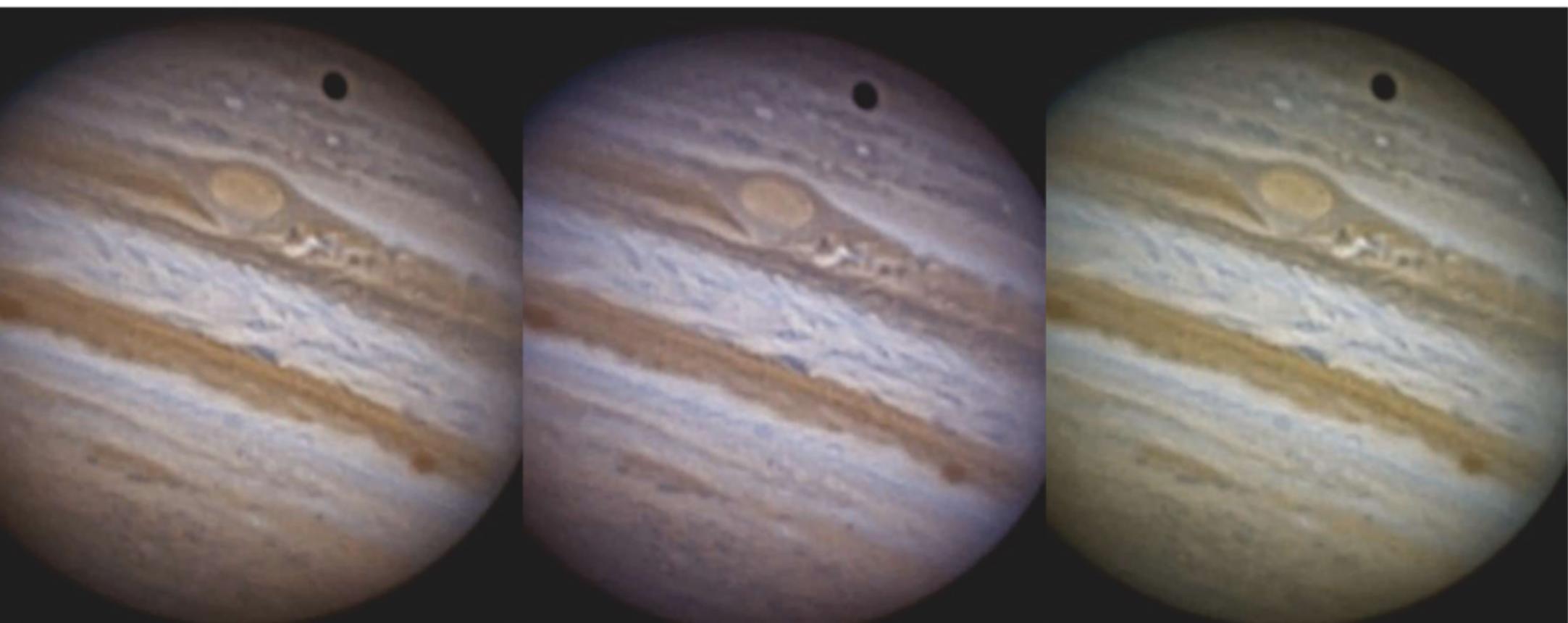
Now, in the surface shot, use a selection tool to select the black sky. Expand the selection by a couple of pixels and then apply a couple of pixels of edge feather to reduce the sharpness. Invert the selection and copy the surface to the clipboard. Paste this into the prominence image and align the edges. You'll now have a shot of the edge of the Sun showing both surface detail and prominence detail, all extracted from the same initial image.



▲ To reveal prominence data move the mid-point slider towards the left-hand peak

COLOUR HANDLING

The best approach to the question of planetary colour



▲ Even for seasoned imagers, it's easy to stray off course when assembling a full-colour image and produce an unrealistic end result

Of all the stages in image processing, colour balancing is the one that can cause the most heated debates. It's often said that if you give 10 planetary imagers the same red-, green- and blue-filtered images of a planet and ask them to assemble them as a full-colour image, you'll end up with 10 completely different final pictures.

This happens because we all have our own individual idea of what a planet's colour should be. As we process, we tend to drag the colours towards this subjective reference until, when it matches our mind's-eye view, we reveal it to the world. But your mind is also quite good at misremembering what you've

seen and it's all too easy to convince yourself that the image you've been working on for the last few hours is perfect, when, in reality, it's way off.

The only way that you can get colour right is to identify a set of external colour benchmarks and work towards these, forgetting the voice in your head that's trying to tell you otherwise. Although this sounds simple, it's not, and even seasoned imagers get it wrong.

The Sun and the Moon are easy to deal with: the Moon's colour is subtle to start with and the Sun's colour is fashionably subjective. By that, we mean that the many colourful images of the Sun taken through white light and specialist filters

are artificially coloured and controlled by current convention rather than reality.

The planets, however, are a different matter – they need careful nurturing to get them right. Wherever possible, colour cameras should be allowed to achieve an auto-white balance for the best results. If the planet's image is dim, turn the gain up using the control software so that the camera can achieve this. For accurate images made up of filtered red, green and blue components, it's important to capture them all at the same saturation level. If not, the end result will show a colour cast. Check your control software documentation to see whether it provides a level meter during capture.

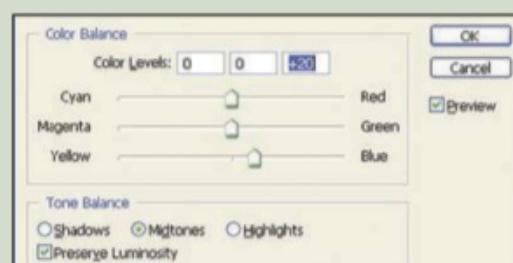
PETE LAWRENCE X7

COLOUR ADJUSTMENT TOOL

Colour balance

Colour balance allows you to adjust the highlights, lowlights and mid-colours of an image. It's easy to get seduced into thinking what you've done looks good when it doesn't, so use this tool with extreme care.

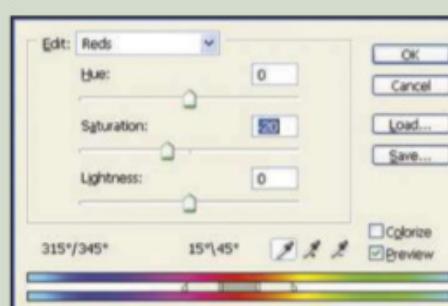
Colour balance is useful for reducing colour casts that make an image appear, for example, too yellow or too red.



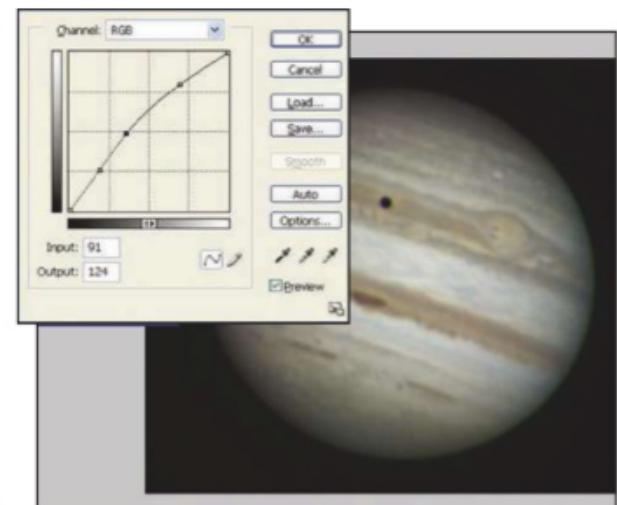
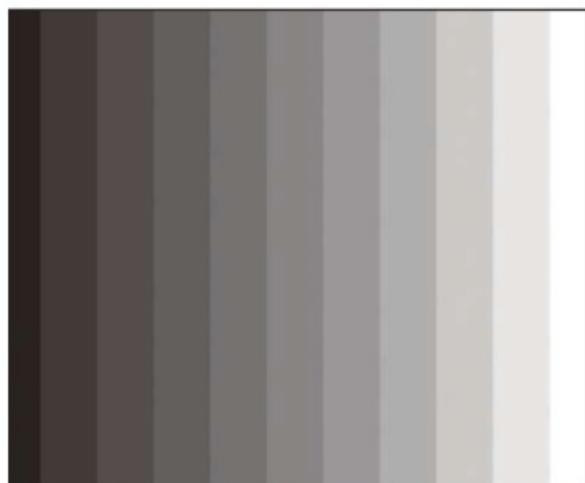
Hue, saturation and lightness

Hue, saturation and lightness (also called brightness or brilliance) adjustments can be used to target specific colours within an image. The hue slider maps the selected colours to a different colour range.

Saturation defines how pure or washed out those colours appear, while lightness changes how bright they appear.

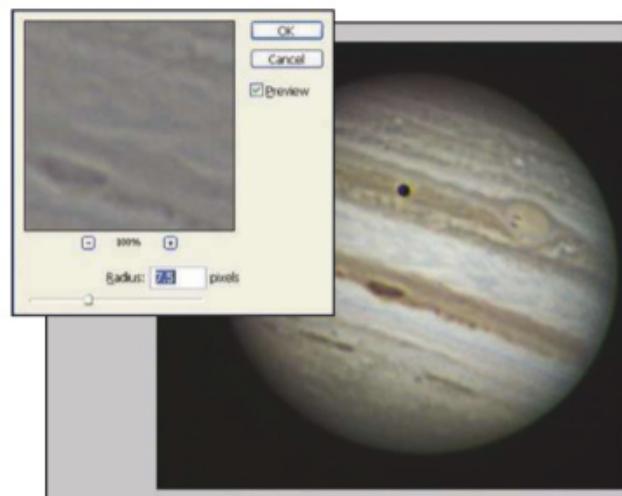


STEP BY STEP: Assemble a full-colour planetary image



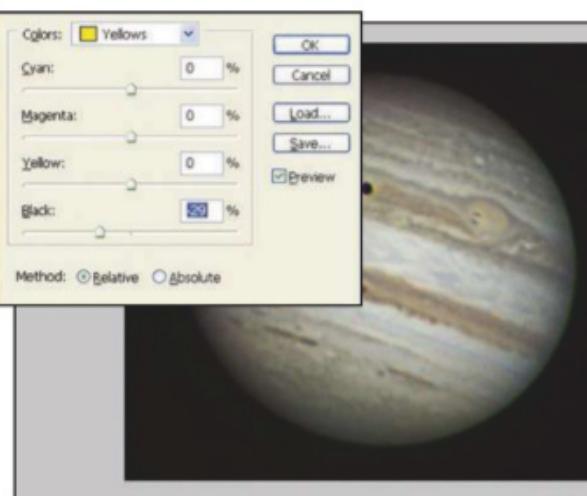
1 Monitor calibration

Before trying to get a good colour rendition of a planet, it's important to check that your monitor is set to display colour properly. There are various online sites to help you with monitor calibration and many monitors come with their own software utilities to help you set them up properly.



2 Image build

Build the RGB image from its components, the filtered red, green and blue images, using the method explained on page 81. If the end result looks grainy, a despeckle or even a weak Gaussian blur can help to reduce noise in the end result. Be careful not to overdo the blur and remove detail.



3 Curves

Duplicate the RGB layer, keeping the original as a reference backup. Open the curves tool and create points at quarter intervals along the adjustment line. Adjust overall brightness with the central point and then, using small movements only, tweak the appearance using the first- and third-quarter points.



4 Sharpen

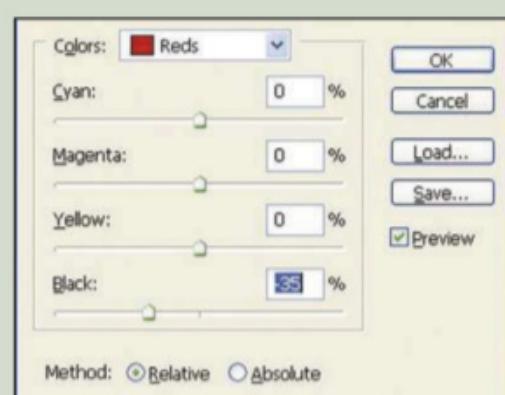
Sharpen using a high-pass filter (see page 86) – this involves duplicating the layer and setting the upper one's blend to overlay. Set the filter's radius to its lowest setting to start with and increase it slowly. Settle on the most natural result. If colours look muted, increase the lower image's saturation.

5 Selective colour

Merge the high-pass/overlay image with the layer below and duplicate the result as a further layer. For images of Jupiter and Mars, this is a good time to experiment with the selective colour adjustment described below: select the yellows and subtly adjust the black slider to reveal hidden detail.

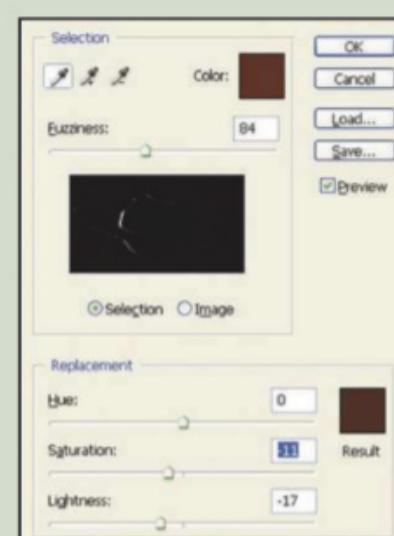
6 Reference

Check you haven't got a colour cast. On Mars, the bright poles should appear off-white with no colour tone. The equatorial belts on Jupiter have a grey-orange tone, while the equatorial zone is slightly off-white. The rings of Saturn should look grey, with the equatorial region a dark straw yellow.



Selective colour

This alters the amount of 'process' colours in the primary colour ranges of the image. Originally intended for colour-correcting photographs destined for printing, selective colour is useful for extracting detail from planetary images too. Selecting reds or yellows and adjusting their black content often works well for Mars and Jupiter.



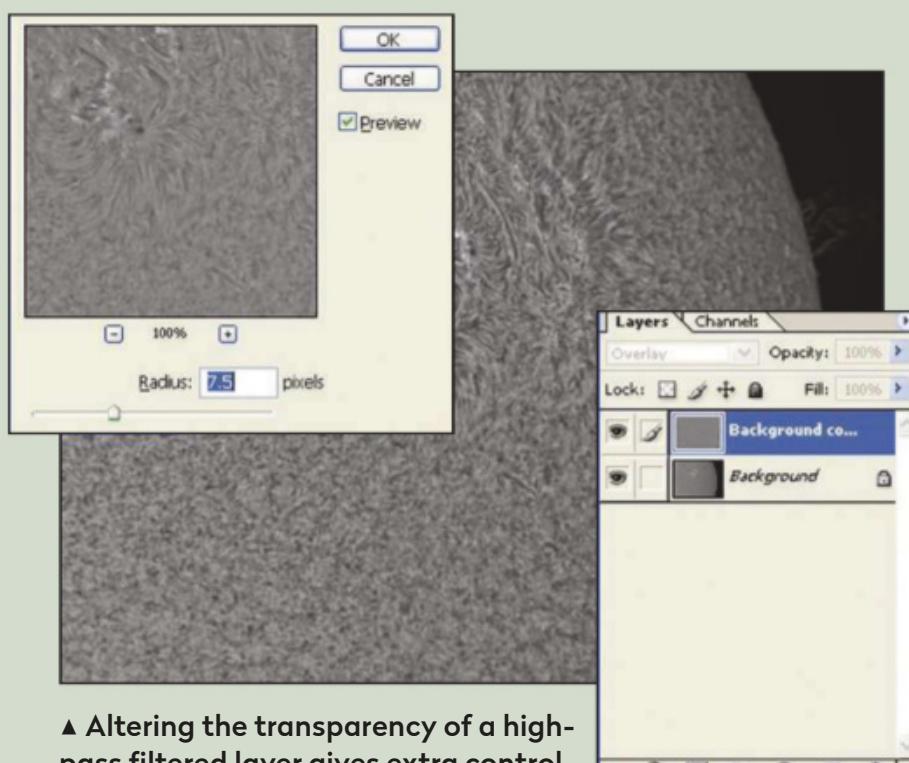
Replace colour

This facility allows you to pick a specific colour that needs to be adjusted in an image, and define how many similar colours will also be affected. Once it's been defined, the hue, saturation and lightness of the range you've selected can be altered. This is especially useful for reducing the impact of unwanted colour artefacts in an image.

ENHANCING DETAIL

Six ways to bring out the best in Solar System images

HIGH-PASS FILTER



▲ Altering the transparency of a high-pass filtered layer gives extra control

The high-pass filter can be used to provide controlled sharpening of any image. In order to use the filter, it's necessary to create a duplicate of the base image as an upper layer. The blend mode of the upper layer is then set to overlay and the filter is applied. Its strength is defined by a value called 'radius' and in some editors, such as Photoshop, changing this value shows an immediate effect on the image.

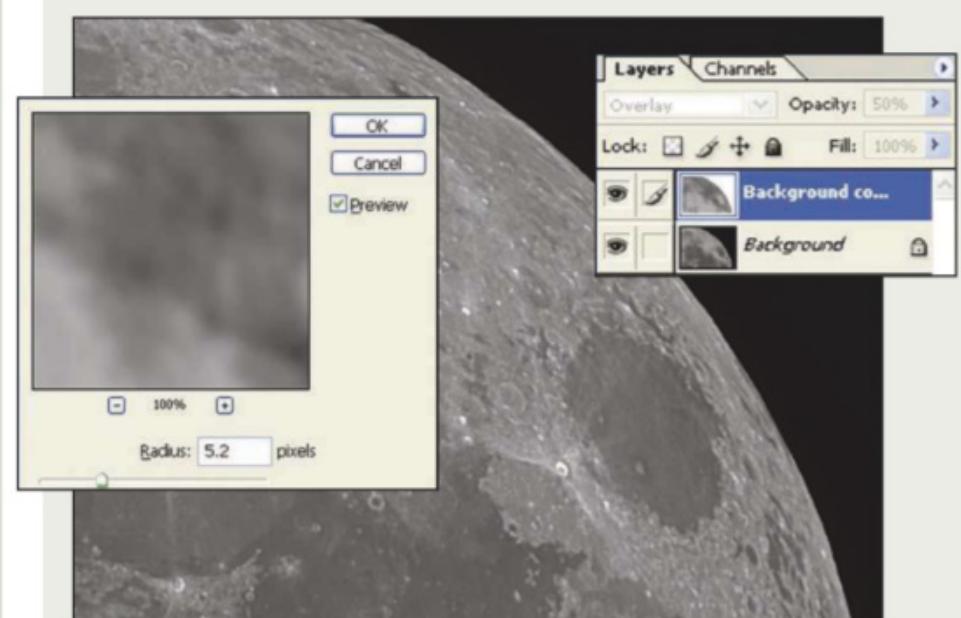
Changing the radius value gives you fine control over how the image is sharpened. It's useful to set the radius low to begin with and then increase its value to taste. As the sharpening element of the image is on an upper layer, adjusting the transparency of this layer provides yet more control over the filter's strength.

ALL PICTURES: PETE LAWRENCE

OVERLAY, INVERT AND BLUR

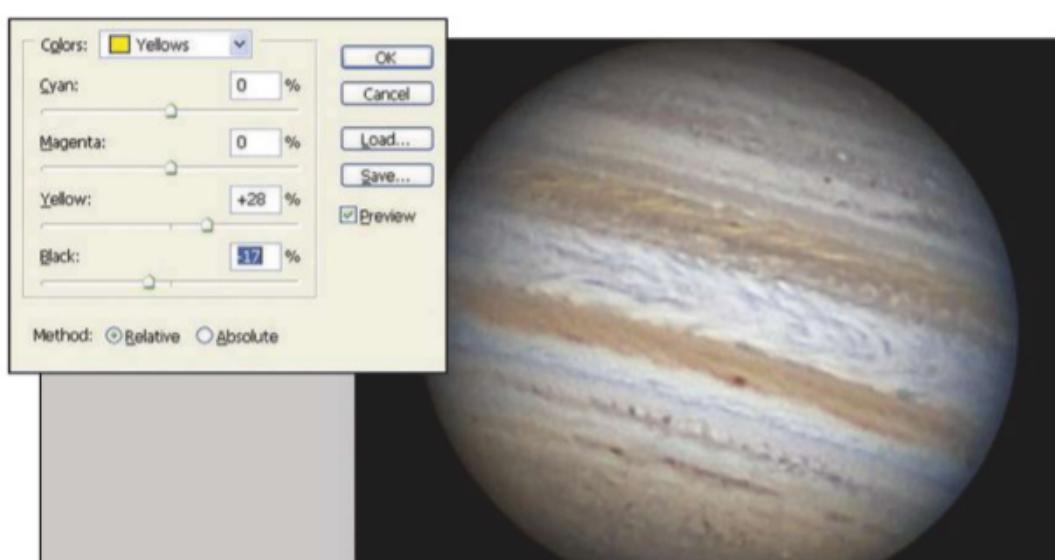
The overlay blend mode can be used to increase the apparent dynamic range in monochrome images by applying it with an invert and blur process. The technique is particularly good for bringing out murky shadow detail on the Moon and can really pull out subtle grey shades on the floors of lunar seas.

It's applied by duplicating the base image, inverting the duplicate upper layer to make it appear negative, making that layer 50 per cent transparent, switching the blend mode to overlay and applying a Gaussian blur. Adjusting the blur helps bring out tonal detail. Once completed, it's not unusual for the image to look full of detail but also a bit flat. Adjusting the contrast slightly and lowering the brightness can then help to restore the image's visual impact.



▲ As well as being suited to monochrome planetary images, this technique also works well on lunar maria

SELECTIVE COLOUR

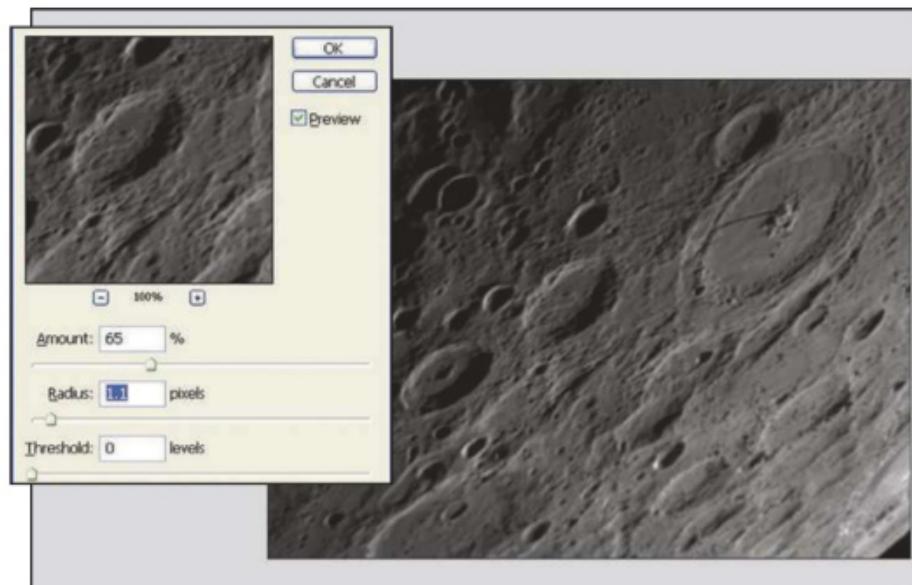


▲ Adjust specific colours without altering your image's overall colour balance

The selective colour adjustment control is a function that has origins in the world of printing. It allows you to select a primary colour group and adjust the colours that contribute to it. In astrophotography, this can be a useful technique to target specific colours and adjust them without affecting the balance of the image.

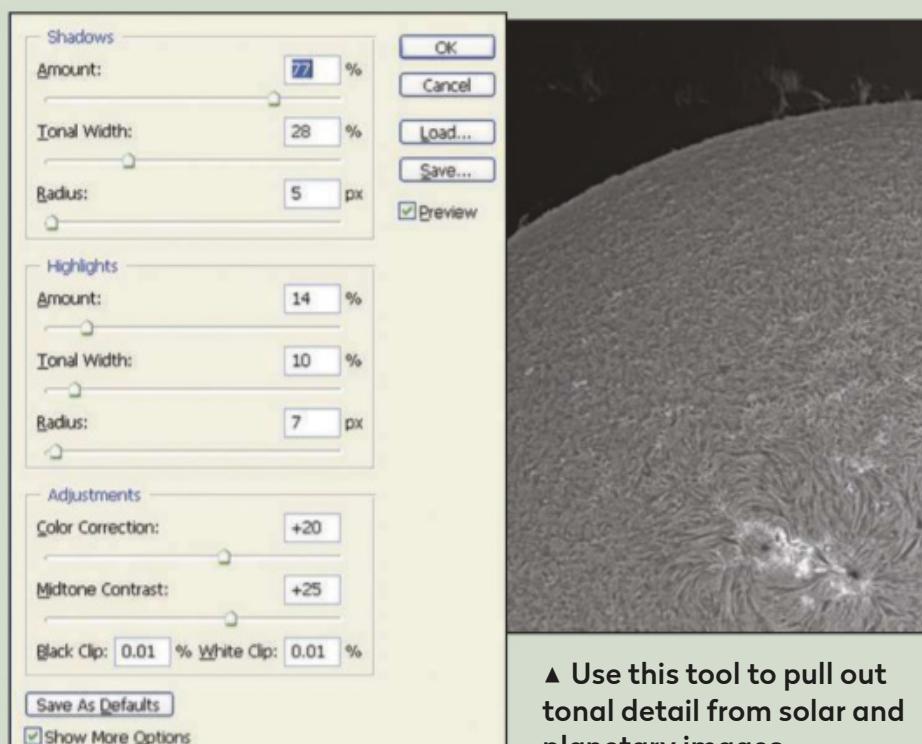
As an example, Jupiter's equatorial belts may contain additional detail that's hidden from view due to a combination of red and yellows. Selecting the yellows and adjusting the sliders of the contributing colours may emphasise and reveal some of this hidden detail. Major shifts in colour should be avoided, but there's normally enough leeway to maintain balance while extracting additional detail.

UNSHARP MASK



▲ Unsharp mask is a filter that benefits from a subtle application

SHADOWS/HIGHLIGHTS



▲ Use this tool to pull out tonal detail from solar and planetary images

The shadows/highlights adjustment tool in Photoshop provides a powerful means of dealing with dark shadow tones and light highlight tones without upsetting the vast majority of the image. Its application is not too dissimilar to the overlay, invert and blur technique described on the previous page, and it's good at pulling out otherwise hidden tonal detail from an image. Photoshop's instant preview makes it easy to experiment with the settings for this tool to help achieve optimum results.

Shadows/highlights is excellent for bringing out hidden detail in lunar shots and on solar images where image detail may have become hidden within the darker regions close to the edge of the Sun. Similarly, it can be used to pull back the edge of a planet that has been badly processed so that it looks as if it simply merges into the background sky.

Photoshop offers two modes for using this tool: basic and advanced. The basic option simply provides two sliders – one for shadows and one for highlights. The advanced setting allows you to define each setting in terms of amount, tonal width and radius.

The unsharp mask filter is a commonly encountered tool for image sharpening, targeting tonal edges in an image. The tool typically has three adjustable values: amount, radius and threshold. Amount controls how much contrast is added to a tonal edge border, while radius affects the size of the edges – the smaller the radius value, the finer the detail that's affected. The two work together, so reducing one setting allows you to increase the other.

The third variable, threshold, effectively defines how much difference there must be between tonal values in order for an edge to be processed. Threshold is particularly useful if your image has large areas with fine noise grain. By setting it slightly higher than 0, you can stop the unsharp mask being applied to these areas.

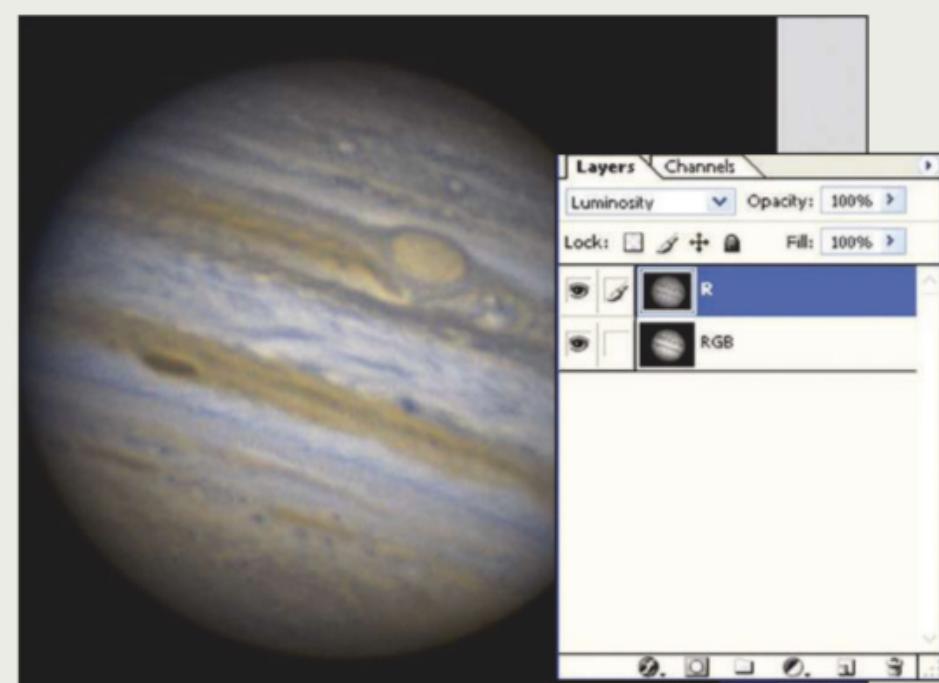
Using the unsharp mask filter is quite addictive, as detail can rapidly become noticeably enhanced. But don't overdo things – a good starting point for amount, radius and threshold is 50 per cent, 0.5 and 0 respectively.

LUMINOSITY

The luminosity of an image defines its spatial detail. When luminosity is combined with colour, the result is a detailed full-colour image. It's possible to target the luminosity component of an image and this presents further options for enhancing detail.

One technique is to add the sharpest filtered image back into the RGB image as a separate layer. Processing this layer to be as sharp as possible and setting its blend mode to luminosity can often create an impressive-looking result. It's common to use the red-filtered image for luminosity, resulting in what's called an R-RGB image. The 'R-' indicates red has been used for luminosity enhancement. Longer wavelength red and infrared (IR) images normally look sharper and offer higher contrast under typical UK seeing conditions and this is why they are chosen.

Luminance layers can alter colour balance, so it's important that any images constructed in this way are appropriately labelled if they're to be used for scientific analysis. Under excellent seeing conditions a sharp G luminance is preferable to an R or IR.



▲ Adding a luminosity layer will increase the fine detail in your images

SOLAR SYSTEM OBJECTS ADVANCED TECHNIQUES

Jupiter is a great planet to practise these techniques on – every tip in this section will work on it



We're now going to look at how to process the Sun, Moon and brighter planets a bit further. First off, we'll take a look at sharpening specific detail in images, as well as how to use blurring tools to keep an image in balance if parts of it start to look unrealistic. From there we'll move on to deconvolution, a processing technique that can – to a certain extent – undo problems that may be introduced by Earth's atmosphere or even your telescope. Although you'd normally

only come across this kind of powerful function in high-end specialist astronomical image processing software, there are options available for general graphics editors too, using plug-ins. A deconvolution process, used with care, can really help you to pull specific detail out of your shots.

We're also going to examine a way you can save time when imaging the planets in colour – by discarding one of the colour channels completely. Don't worry, you'll still end up with a stunning image.

Plus, we'll cover derotation and using your processed still images to create animations: it's amazing how much life a bit of motion can breathe into Solar System images.

OUR EXPERT



Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

WHAT YOU'LL LEARN

89 Wavelet sharpening

Sharpen different levels of detail in your images with this clever trick

90 Sharpening and blurring

Use two opposing tools to remove digital noise from your images

91 Deconvolution

Remove optical distortions from your images and make your blurred stars pin sharp

92 Synthetic colouring

Who needs green? Cut imaging times by combining colour channels

93 Derotation

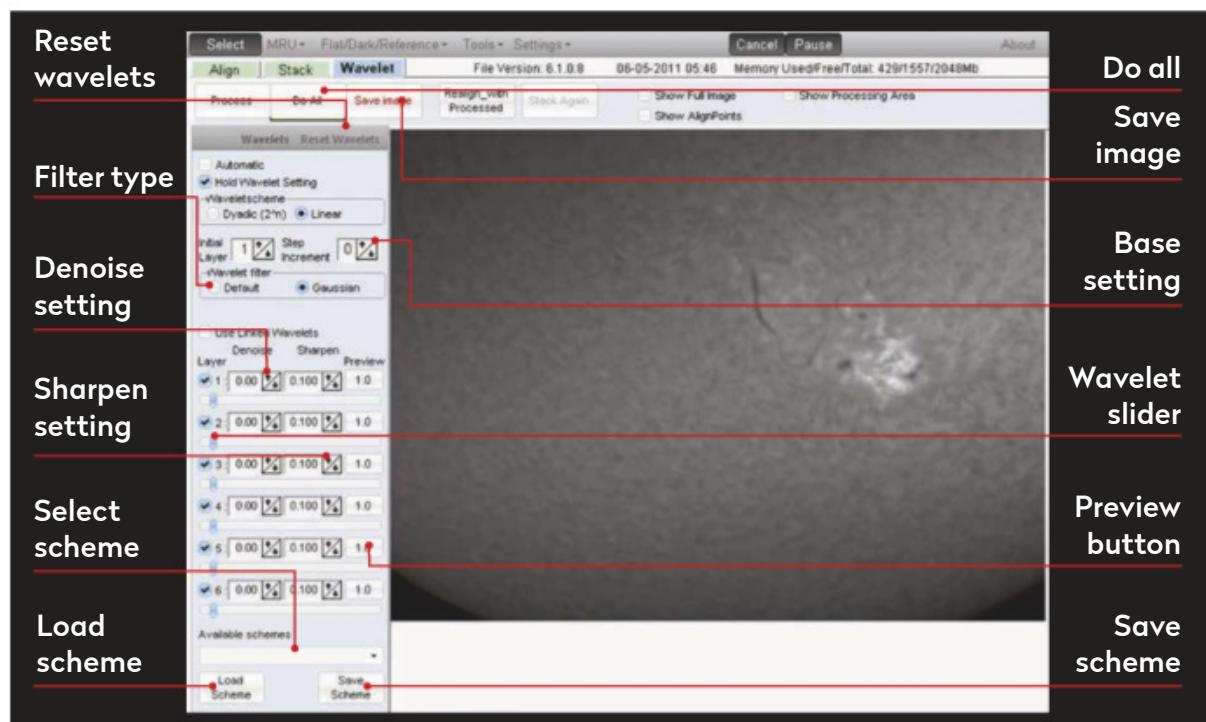
Turn back time and reverse a planet's spin with this processing technique

94 Animation processing

The Universe doesn't stand still, so why should your images of it?

WAVELET SHARPENING

How to bring out specific details in your stacked images

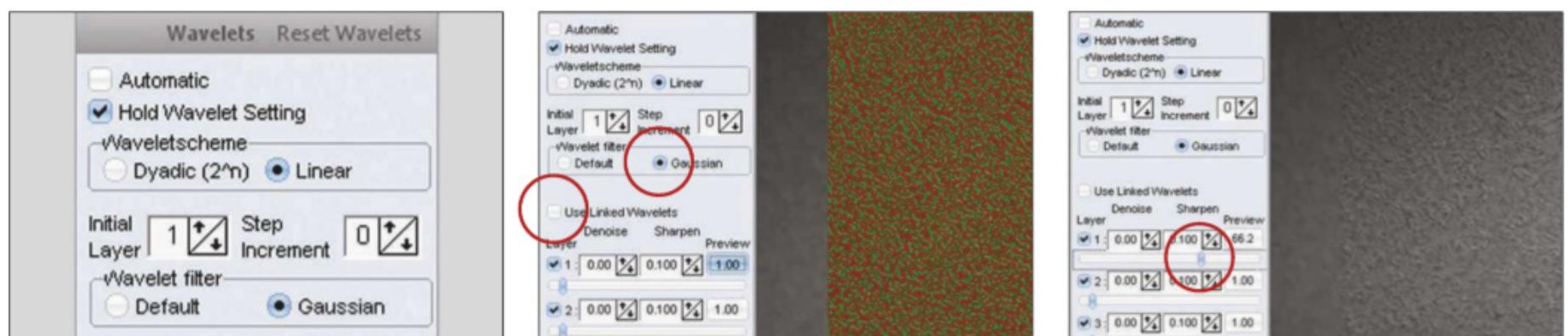


▲ The main controls of RegiStax's wavelet window give powerful sharpening possibilities

Wavelet sharpening is a technique that enables you to target and sharpen specific scales of detail within an image. This is useful if you want to sharpen mid-sized features while leaving fine detail – including noise – alone, or vice versa. Wavelet sharpening is available in various image processing programs and there are also plug-ins for graphics editors that don't have it as standard.

Many people first encounter wavelets when using the freeware registration and stacking application RegiStax. In this program, wavelets sit at the end of the main processing run and are used to enhance the detail in the final processed image. Below, we look at the wavelet function in this free piece of software.

STEP BY STEP: Targeted sharpening with RegiStax wavelet tools



1 Initial settings

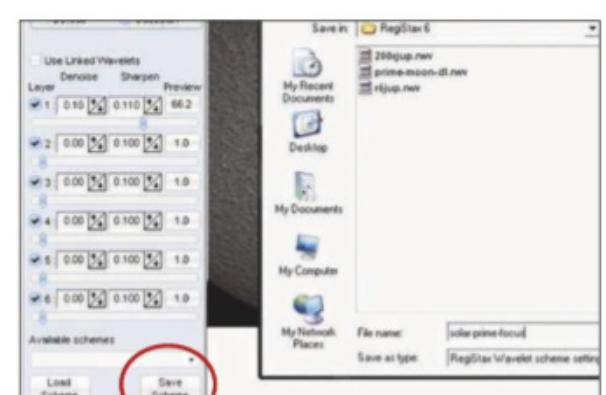
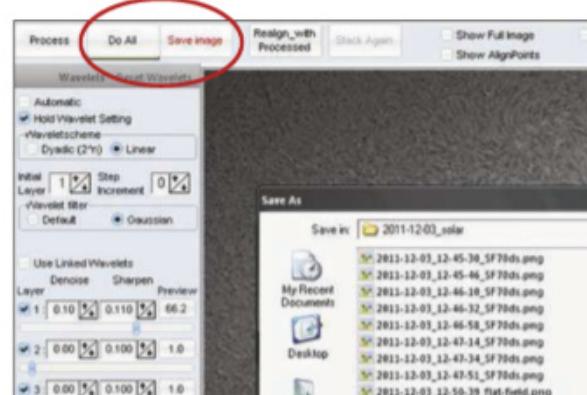
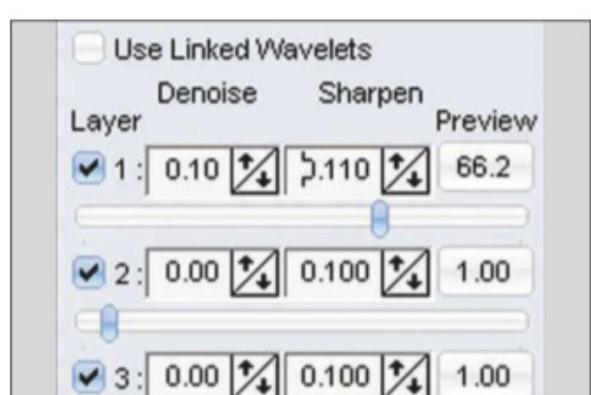
If you're processing several AVI files, check the Hold Wavelet Setting box. Set Waveletscheme to Linear, Initial Layer to 1 and Step Increment to 0.

2 Preview

Set Wavelet Filter to Gaussian and uncheck Use Linked Wavelets. Click the preview button for each slider and find the first that deals with detail, not noise.

3 Keep it natural

Move the slider you identified in Step 2 to the right, monitoring its effect. Don't overdo the sharpening. Check the effect the next slider has too.



4 Gently does it

The slider's Denoise and Sharpen values can be adjusted to reduce noise and boost sharpening, but use them sparingly. If you get in a mess, click Reset Wavelets.

5 Apply and save

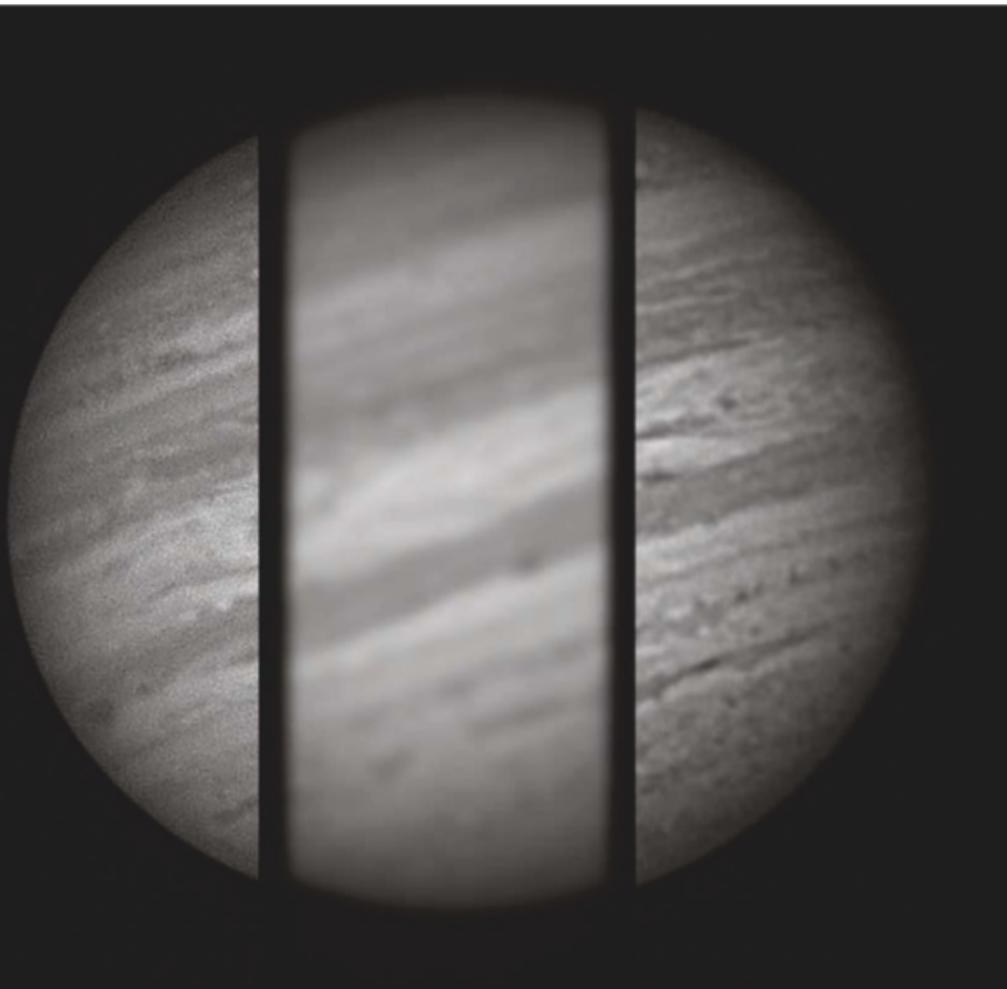
Click Do All, then Save Image. Save as a 16-bit PNG or TIFF file. Saving a non-wavelet-sharpened result as a FITS file lets you open it to wavelet sharpen later.

6 Save as a scheme

If you're processing a lot of AVIs that need wavelet sharpening, click the Save Scheme button and save the settings to a file that can be reloaded later.

SHARPENING AND BLURRING

How two seemingly opposing tools can be used together



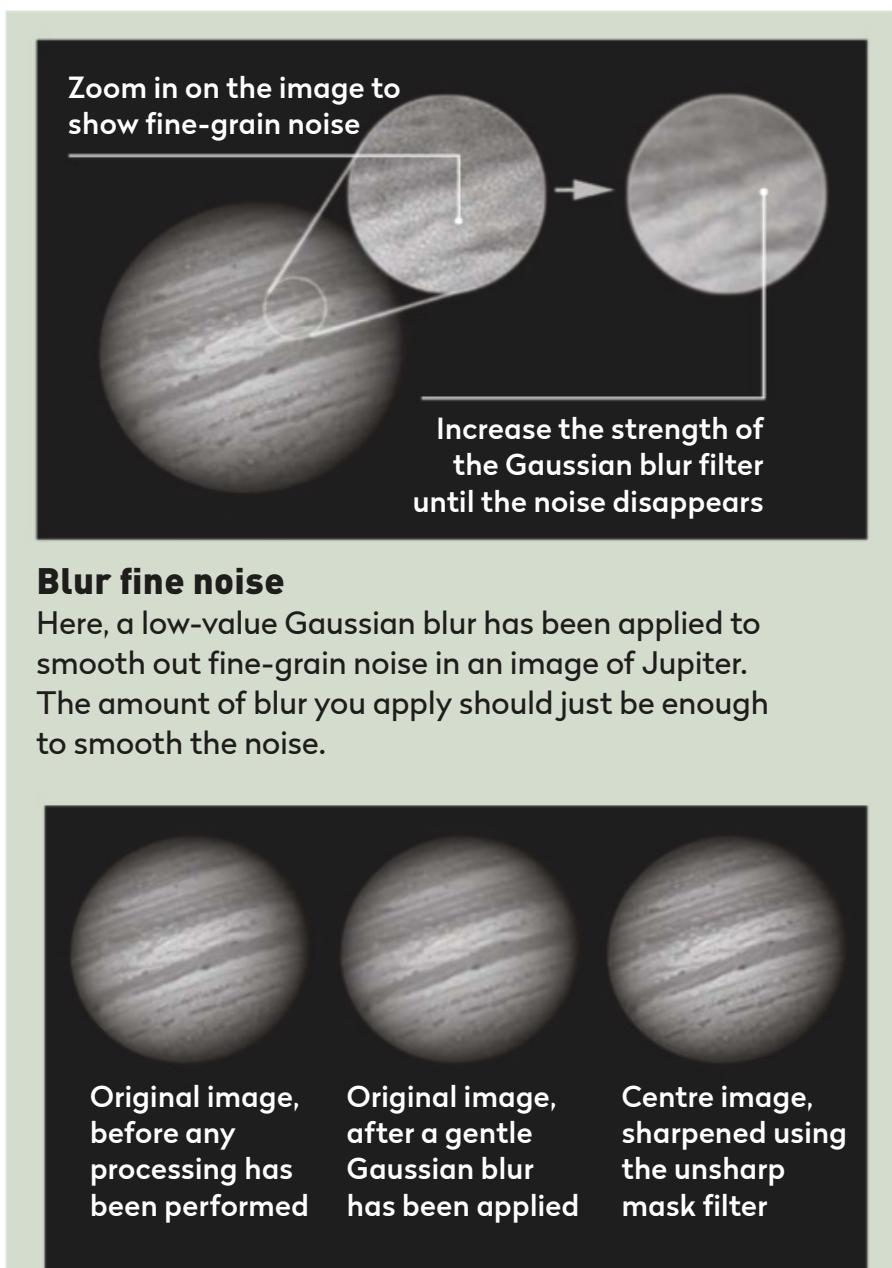
▲ A noisy original image (left) is blurred slightly to remove noise (centre) and then sharpened to give an improved final image (right)

Two commonly used techniques in image processing are sharpening and blurring. We covered some sharpening methods in the previous section, but we're going to revisit them here to show you how they can be used together with a suitably targeted Gaussian blur.

At first glance, it may not be immediately obvious what good blurring can do to an image. After all, when you've tried to get the sharpest image possible, why would you want to blur the detail in it? But there actually are plenty of good reasons to do this. For example, blurring can restore a natural look to images that look a too sharp. Similarly, blurring can help to overcome extremely fine noise in an image, which may otherwise end up being sharpened along with everything else. Here, applying a Gaussian blur – adjusted to target the point where the noisy regions disappear and look smooth – can work wonders. The same technique can also work for images that, for various reasons, may show a weak repeating pattern noise.

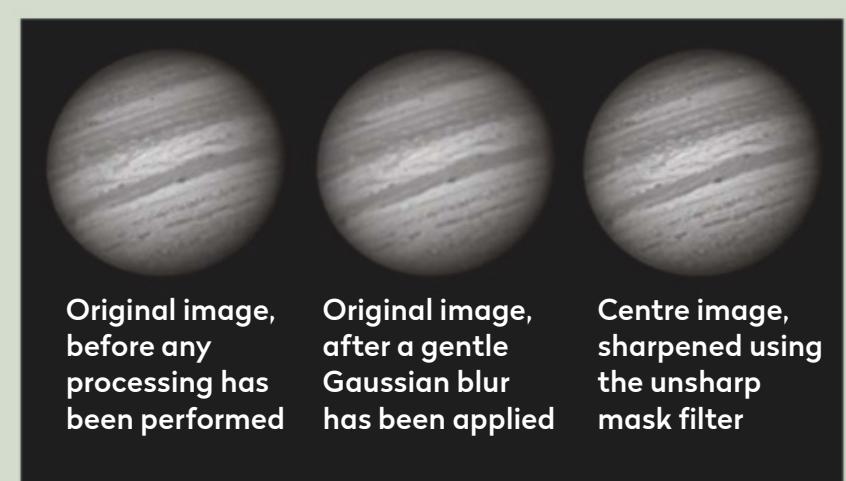
The skilful and balanced application of both sharpening and blurring can help to bring out every last ounce of detail from an image, while still allowing you to keep the end result looking natural and pleasing to the eye. A layered photoediting program, such as Photoshop or GIMP, provides another powerful way to control the intensity of sharpening or blurring. By duplicating an image's original layer, it's possible to work on the upper duplicate, possibly even 'overcooking' the strength of the filter used. Varying the transparency of this upper layer then enables you to control how much of it is applied.

ALL PICTURES: PETE LAWRENCE



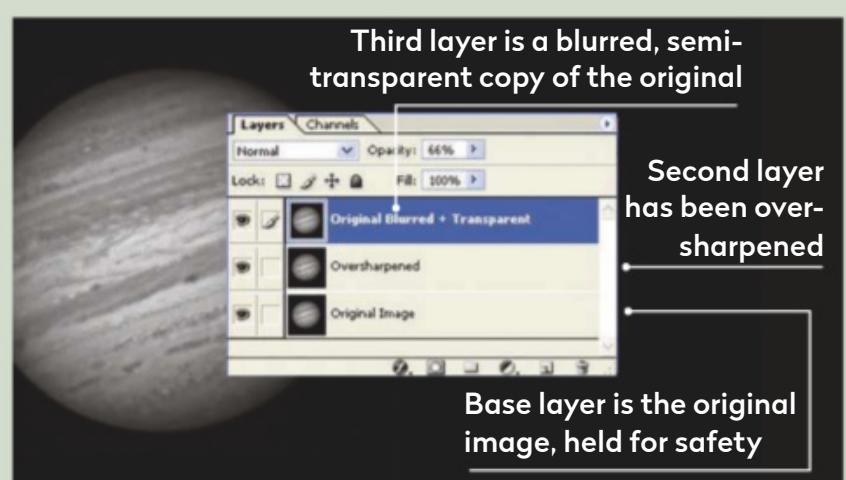
Blur fine noise

Here, a low-value Gaussian blur has been applied to smooth out fine-grain noise in an image of Jupiter. The amount of blur you apply should just be enough to smooth the noise.



Sharpen fine detail

With the fine noise detail removed, you can apply a sharpening process such as the one provided by the unsharp masking tool. With this, fine detail in the image can be sharpened without the risk of enhancing unwanted noise.



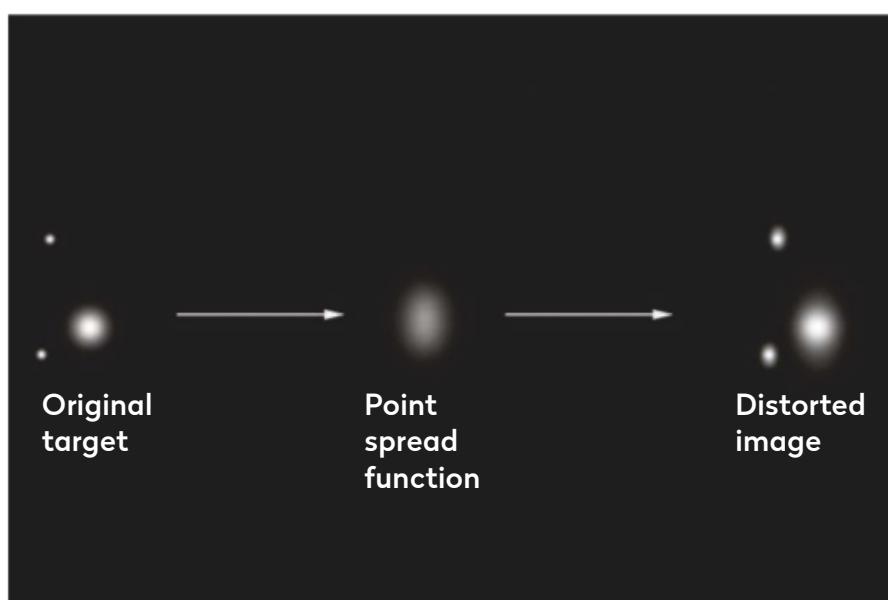
Fix over-sharpening

Blurring can make an over-sharpened image look more natural. Create an upper layer using the original image. Blur it so that fine detail is almost lost, then change the transparency of the upper layer so that the sharpened version shows through.

DECONVOLUTION

A powerful process for rescuing blurred, distorted images

What deconvolution does



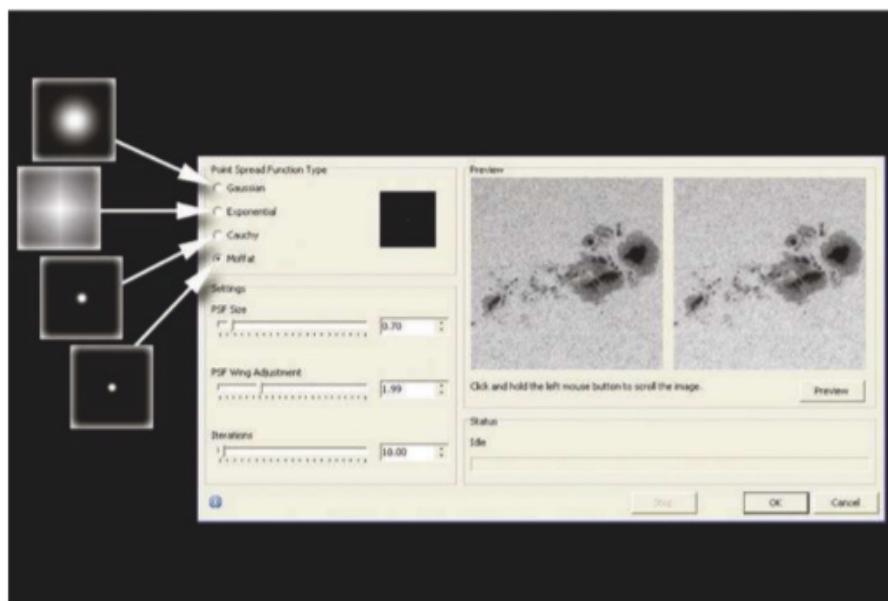
Deconvolution is a software process that reverses the effects of distortion in an optical path to produce an image that looks closer to the original. In astrophotography, distortion, or convolution, results from light passing through Earth's atmosphere as well as encountering errors in your telescope's optics. Deconvolution aims to undo both of these effects. The process that creates the distorted final image is known as the point spread function – its effect is shown in the image above. MaxIm DL, Astra Image, ImagesPlus, Photoshop (via plug-ins), GIMP (via plug-ins), AstroArt and IRIS all offer deconvolution.

Different types of deconvolution



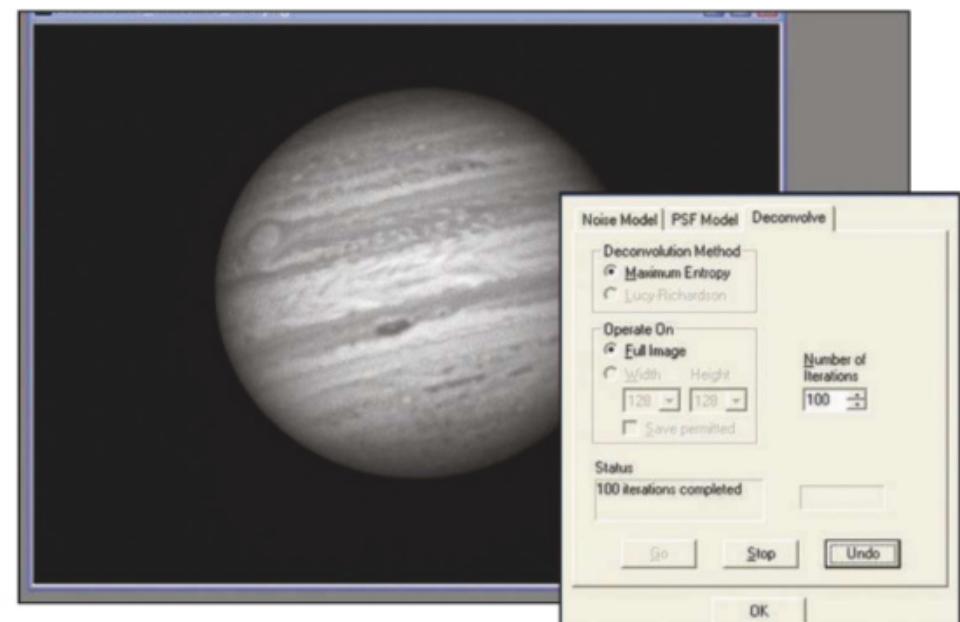
To deconvolute an image, you first need to define the nature of the point spread function. If the point spread function is unknown, you can apply a 'best guess' and see how well it works. This is known as blind deconvolution and is easier for images that contain stars than for images of extended objects such as planets, galaxies or nebulae. Two common deconvolution routines are Richardson-Lucy deconvolution and Van Cittert deconvolution, although there are others. Each method varies, but essentially the main parameters define the shape of the point spread function and how many times the routine is run.

Deconvolution parameters



Deconvolution settings vary, but their main function is to define the shape of the point spread function. A Gaussian point spread function, for example, defines distortion that increases from its central point with a smooth 'Gaussian' profile. Other types may define a sharper or flatter point spread. Begin with the Gaussian setting and experiment. The size of the point spread function should be matched to the image detail you're attempting to recover. Start small and experiment by working up. The number of iterations should initially be set low, around five to 10 runs.

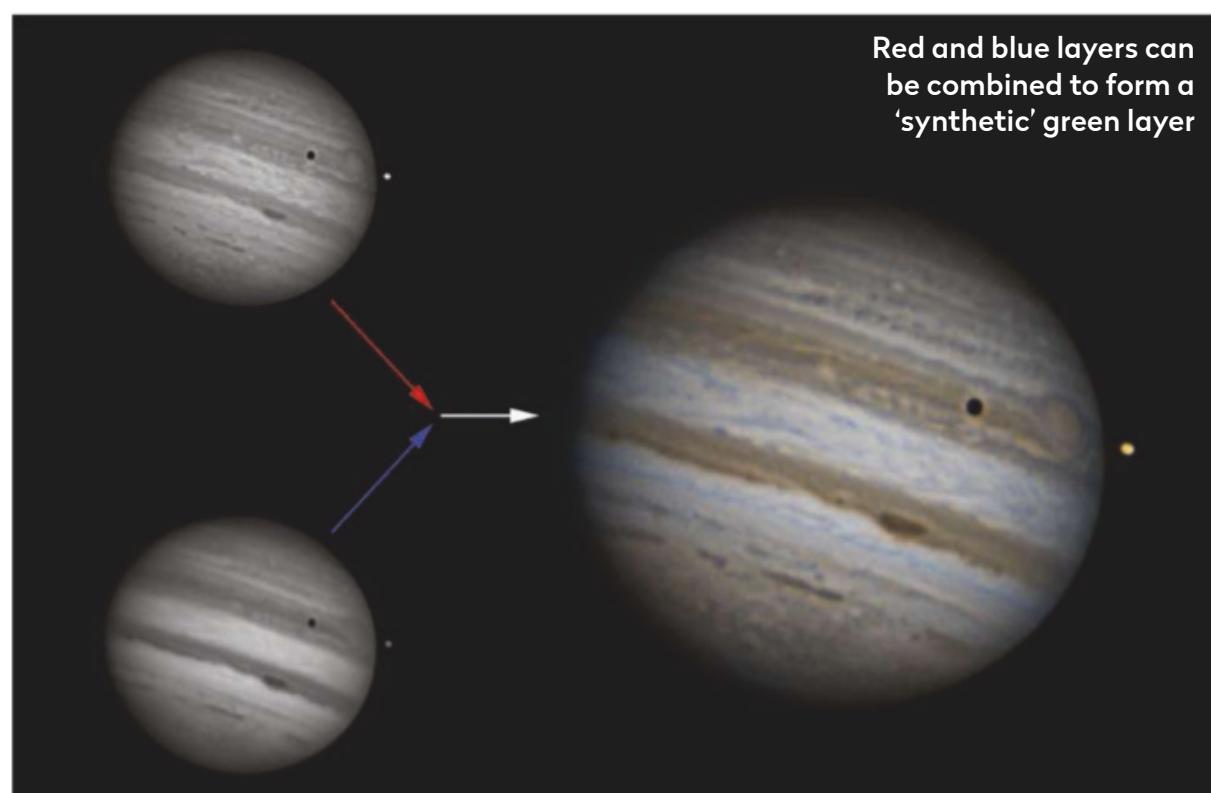
The maximum entropy method



'Maximum entropy deconvolution' is a powerful version of the process that tries to restore an image iteratively. It can be used to correct for poor tracking or collimation. One trick that can work for maximum entropy processing of planetary images is to move the scope so it's pointing at a star bright enough to be recorded with the camera and take an AVI of that too. Register and stack the star without further sharpening, then cut and paste it next to the planet image to give the maximum entropy process a reference – a star that needs to be taken back to a point source.

SYNTHETIC COLOUR PROCESSING

A useful way of cutting RGB imaging times by a third

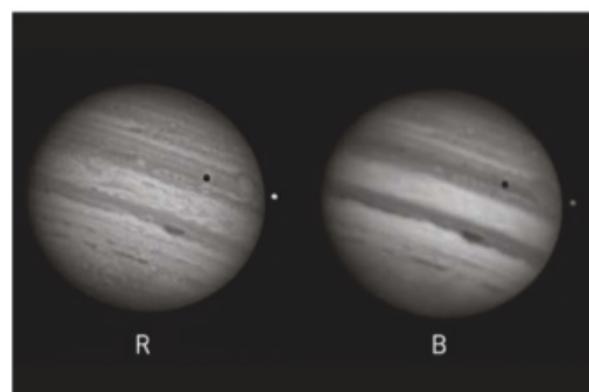


Red and blue layers can be combined to form a 'synthetic' green layer

Unlike many objects in the night sky, some of the planets can be rather challenging to image, because they rotate quite quickly. This is especially awkward if you're imaging with a mono camera through red, green and blue (RGB) filters – you have to find time to image the planet three times, just to get enough captures to create one full-colour image.

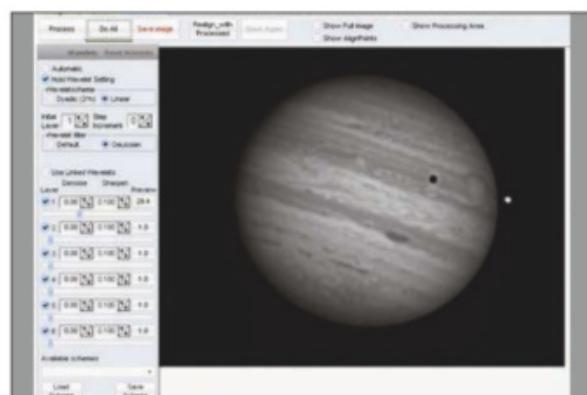
If you take too long imaging Jupiter, Mars or Saturn, you'll introduce motion blur in the final picture. But it's possible to speed things up by missing out one of the filter colours completely, recreating it from the other two captures. Although this may seem somewhat drastic, it's surprisingly effective on Mars and Jupiter, producing results that are hard to differentiate from full RGB images in terms of detail.

STEP BY STEP: Create a full-colour image from two channels



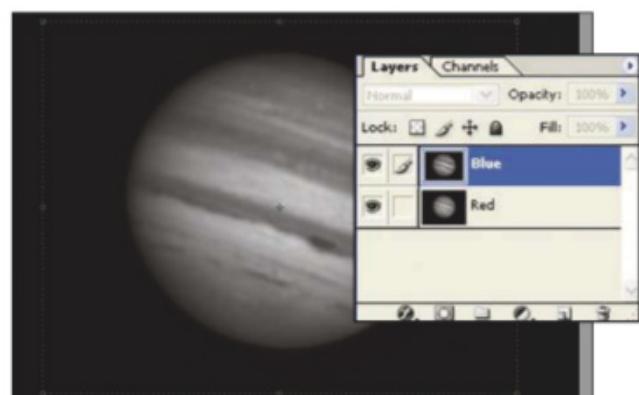
1 Leave out the green

The process begins at the telescope where, for Jupiter and Mars, you capture just the red (R) and blue (B) filtered images, leaving out the green (G) filter completely.



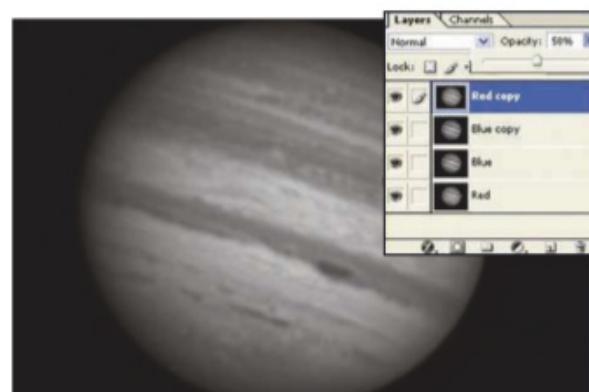
2 Register and stack

Process all the captured image sequences using your favourite registration and stacking software. Apply a gentle wavelet sharpen (see page 89) at the end of each processing run.



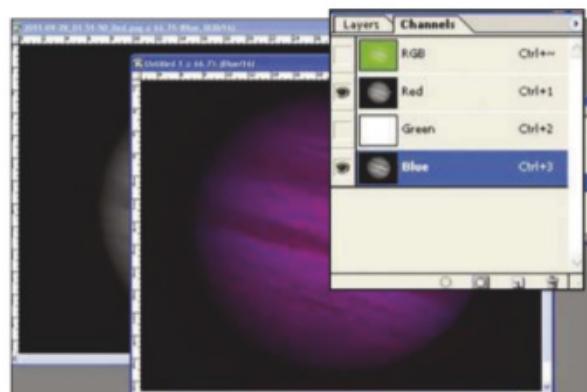
3 Load as layers

Select two sequential RB images and load as separate layers into a graphics editor. Align both images and name the layers 'Red' and 'Blue'. Remove any edge gaps by cropping.



4 Duplicate and merge

Duplicate the Red and Blue layers and bring the duplicates to the top of the stack. Make the top one 50 per cent transparent and merge them. Label the new layer '(Green)'.



5 Switch to channels

Create a blank RGB image with the same dimensions and paste the Red, Blue and (Green) images from the working image into the blank's R, G and B colour channels.



6 Activate

Make sure the RGB channel is selected to automatically activate all the channels. Then adjust using levels and curves to bring out the image's full colour potential.

DEROTATION

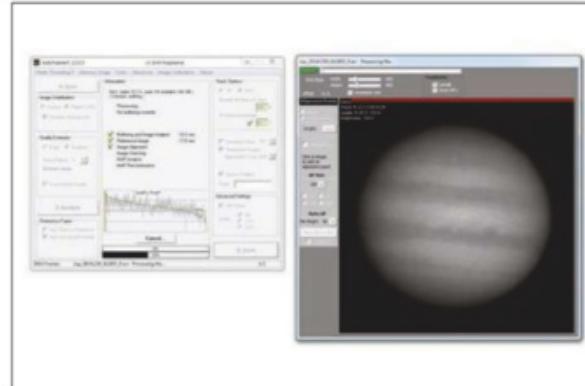
Remove the effects of spin from your images

STEP BY STEP: *Battle blur to retrieve planetary detail*



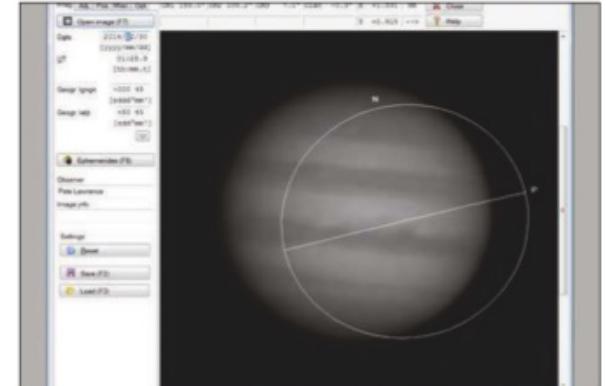
1 Capture

Use a mono high-frame-rate camera with RGB filters to take several 'normal' duration captures using each filter. For example, take five R, five G and five B captures, each 60 seconds.



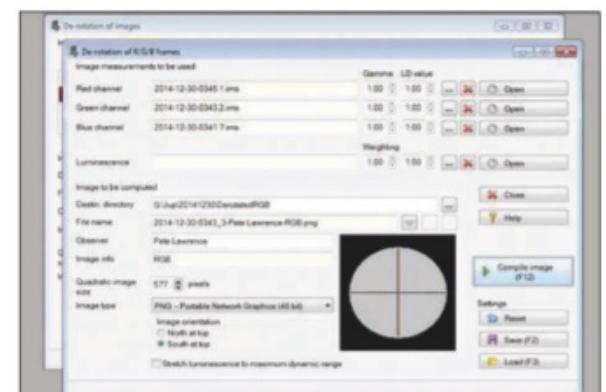
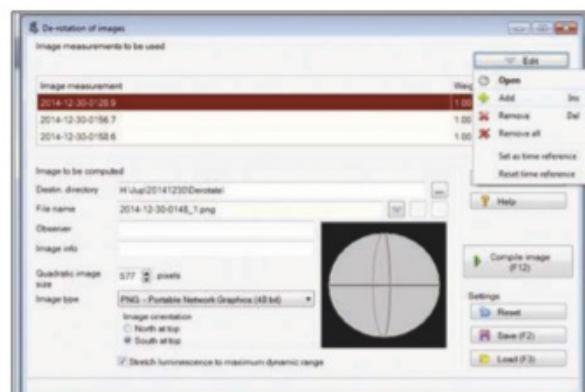
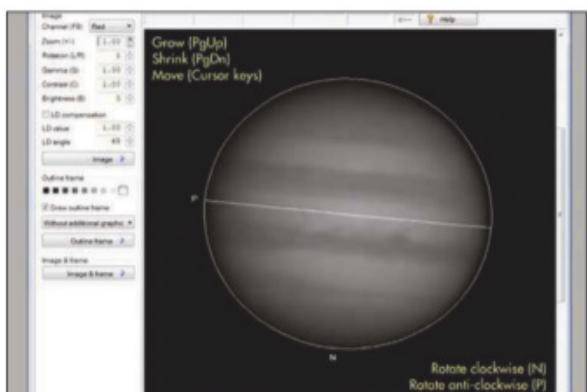
2 Stack

Process each capture using your favoured registration and stacking software. Save the non-wavelet-sharpened result, including the date, time and filter used in the filename.



3 Open in Winjupos

In WinJupos (we used v10.1.15), select Recording Image Measurement. In the Imag. tab, click Open Image and select a processed file. Enter details such as date and time.



4 Match orientation

In the Adj. tab use Outline frame > Automatic detection. Fine-tune with N/P/PgUp/PgDn keys. Save an IMS file into a folder named by filter. Repeat for all images.

5 Derotate

Select Tools > De-rotation of images... then Edit > Add. Select all IMS files in the folder. Check other settings and click Compile image. Note where these files are saved.

6 Compile image

Next, select Tools > De-rotation of R/G/B frames... Click the '...' button for each channel and load appropriate derotated IMS files. Finally, click Compile Image.

Capturing details on fast-rotating planets such as Mars and Jupiter presents a problem: take too long to image them and their features blur when you apply registration-stacking processes. But keeping the captures short limits the number of frames available, so noise will become more of an issue.

One way around this is derotation. Here, software is used to stop a planet rotating and hold its features in the same relative position. With this technique, it's possible to spend more time capturing image sequences without the final result ending up as a blurred mess. The most commonly used derotation process is available in the freeware application WinJupos.



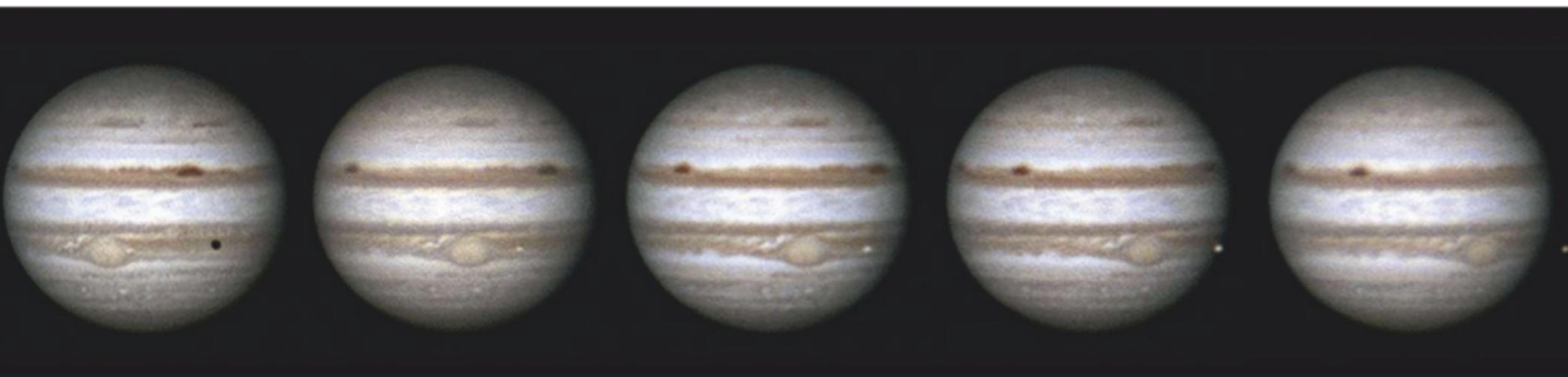
Derotation can be used to effectively lock the features of fast-spinning planets into a fixed position

ANIMATION PROCESSING

Add a little movement to bring your astro images to life



▲ The rotation of Jupiter recorded over two hours as the colossal storm known as the Great Red Spot passes across the face of the planet



▲ The Galilean moon Io can be seen in front of Jupiter after transiting the Great Red Spot; its shadow can be seen in the first frame

Some bodies in the Solar System change their appearance over very short timescales. Mars, Jupiter and Saturn fall into this category because their fast rotations drag their surface features around their globes at a frenetic pace. The Sun viewed in the hydrogen-alpha is another good example, as here features can change appearance in minutes or even seconds.

Capturing these changes in a sequence of still images and presenting them in a strip or grid display can be a great way to show the changes. But the images really come to life when they're put together in an animation. And by doing so you can produce results that far exceed your expectations.

There are many ways to produce animated sequences and just as many ways to store them. One popular technique is to produce what's known as an animated GIF file, GIF being a web-friendly file format that supports animation. A movie file is another way to show motion and the freeware PIPP (Planetary Image PreProcessor)

application can create AVI movie or GIF files from processed still images. The benefit of using a program such as PIPP is that it can remove a lot of the hard work you'd otherwise need to do to create a smooth-flowing sequence of aligned frames.

A successful animated sequence starts at the point of capture. Here, you must decide on how many captures to take, the interval between each one and how long each capture is going to last. The answers to these questions are also affected by external factors such as the amount of free space on your hard drive, the highest uncompressed frame rate your camera can achieve, the image scale or magnification used and the nature of the object or event you're trying to capture.

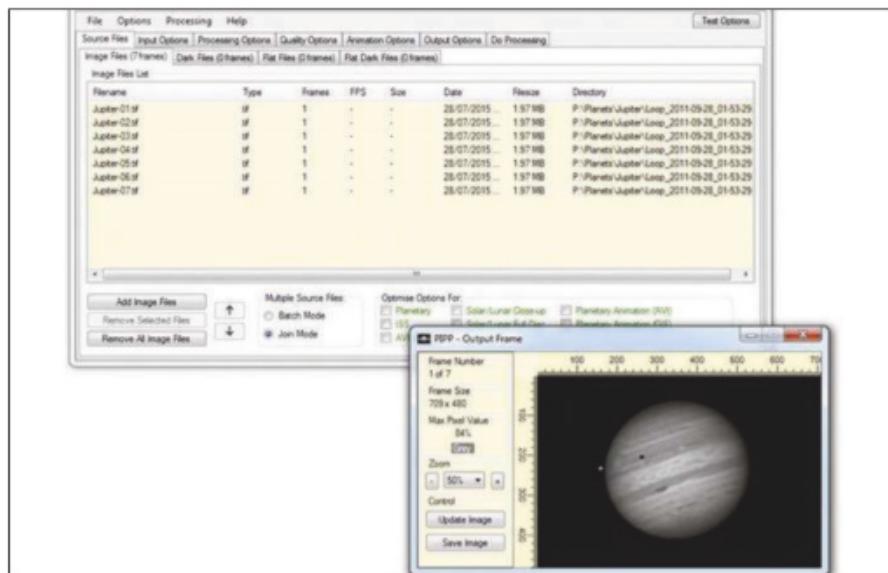
A sequence of 30-second captures of Jupiter, taken at one-minute intervals for an hour, will show about a tenth of the planet's rotation and generate 60 capture files, each 30 seconds long. Processing these files will take a while manually, but batch processing can help

enormously. This is something that another freeware program, AutoStakkert, is particularly good at.

You can load AutoStakkert with a batch of capture sequences, simply by dragging them onto the main program window. You'll need to tell AutoStakkert how to process the first capture and then it'll happily work through the rest. One benefit of AutoStakkert is that it can create pre-aligned results. PIPP can also be used to build animations from non-aligned images thanks to its Enable Surface Stabilisation option (found in the Processing Options tab).

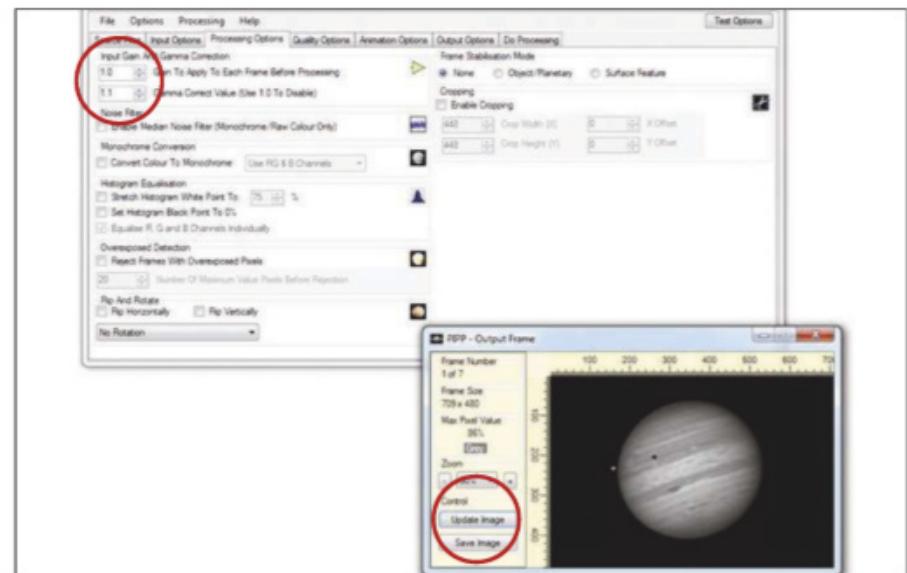
Once you're in possession of the final processed stills, the exciting process of creating the animation can start. PIPP can output in a variety of different formats including animated GIF, which is ideal for inclusion on a website, or as an AVI movie file that can be uploaded to a video sharing site such as YouTube. It's well worth getting to know PIPP's powerful options, so follow our step-by-step guide to get started. As ever, don't be afraid to experiment.

STEP BY STEP: How to create an animation from a sequence of planetary captures using PIPP



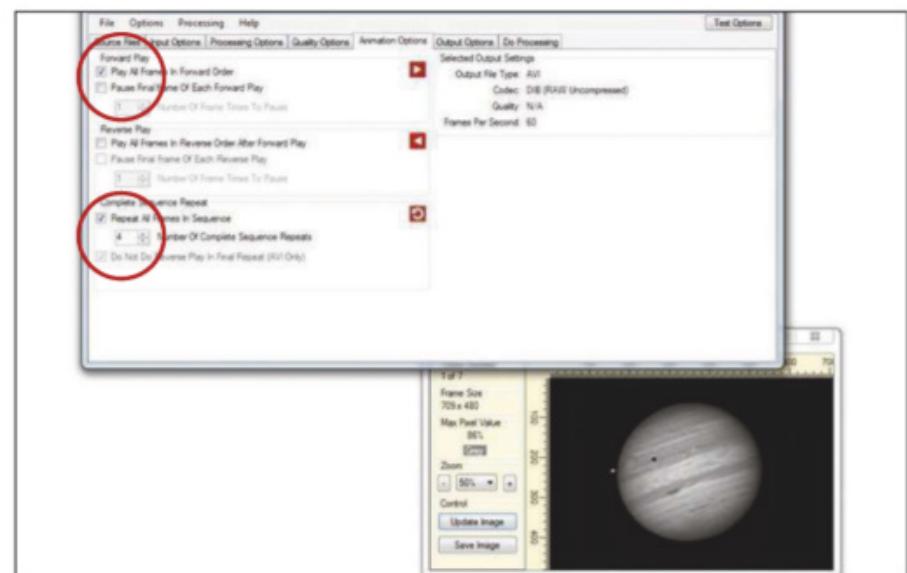
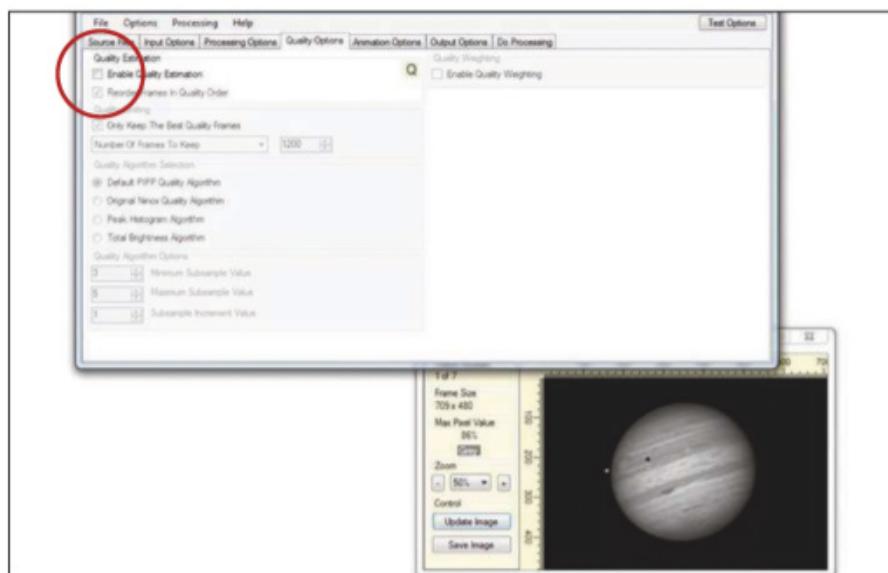
1 Add image files

Open PIPP and click Add Image Files. Navigate to where your still images are located and select those you want to be used in the final animation. The images should ideally all be the same size.



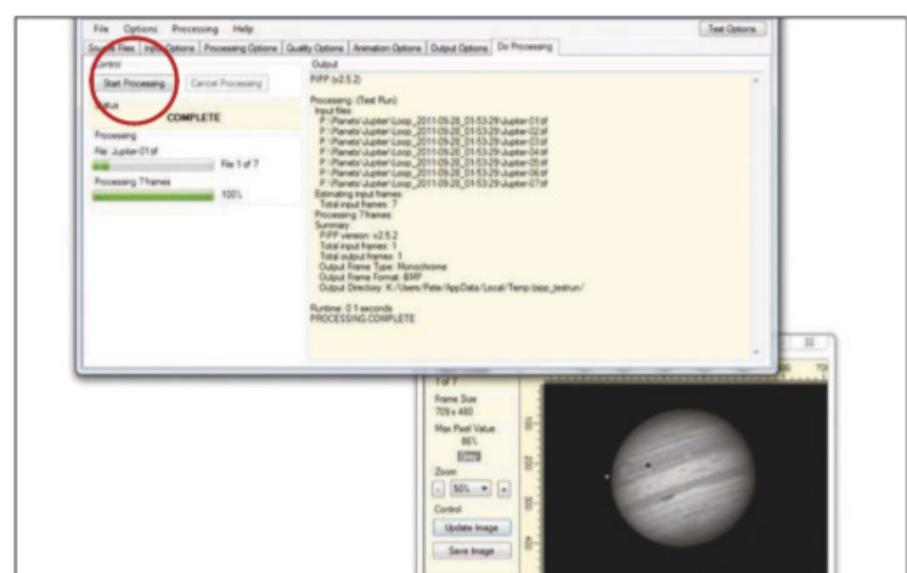
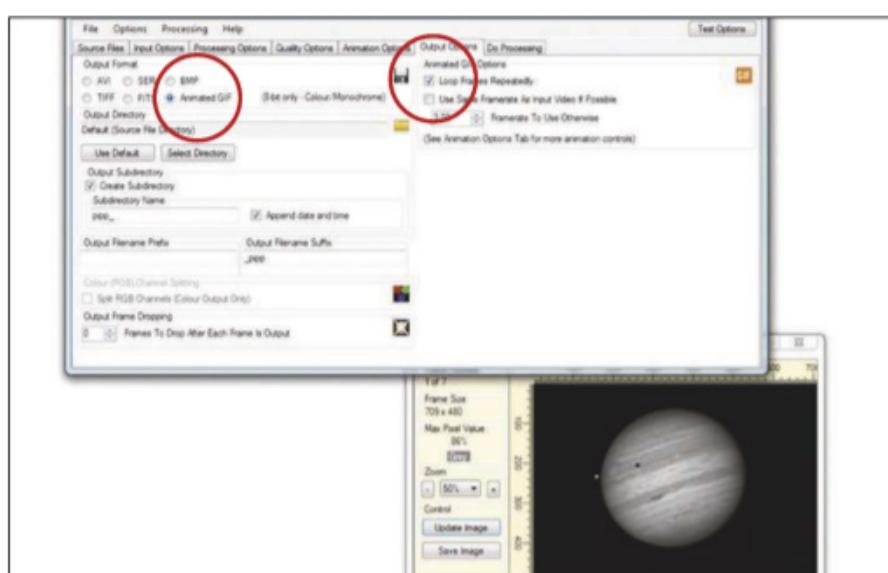
2 Brightness and contrast

It's possible to tweak brightness and contrast by altering Input Gain and Gamma Correction from the Processing Options tab. You can preview changes by clicking the Update Image button.



3 No need to estimate

Untick Enable Quality Estimation in the Quality Options tab. This is for when PIPP pre-processes capture sequences before registration and stacking, which isn't needed for an animation.



5 Loop repeatedly

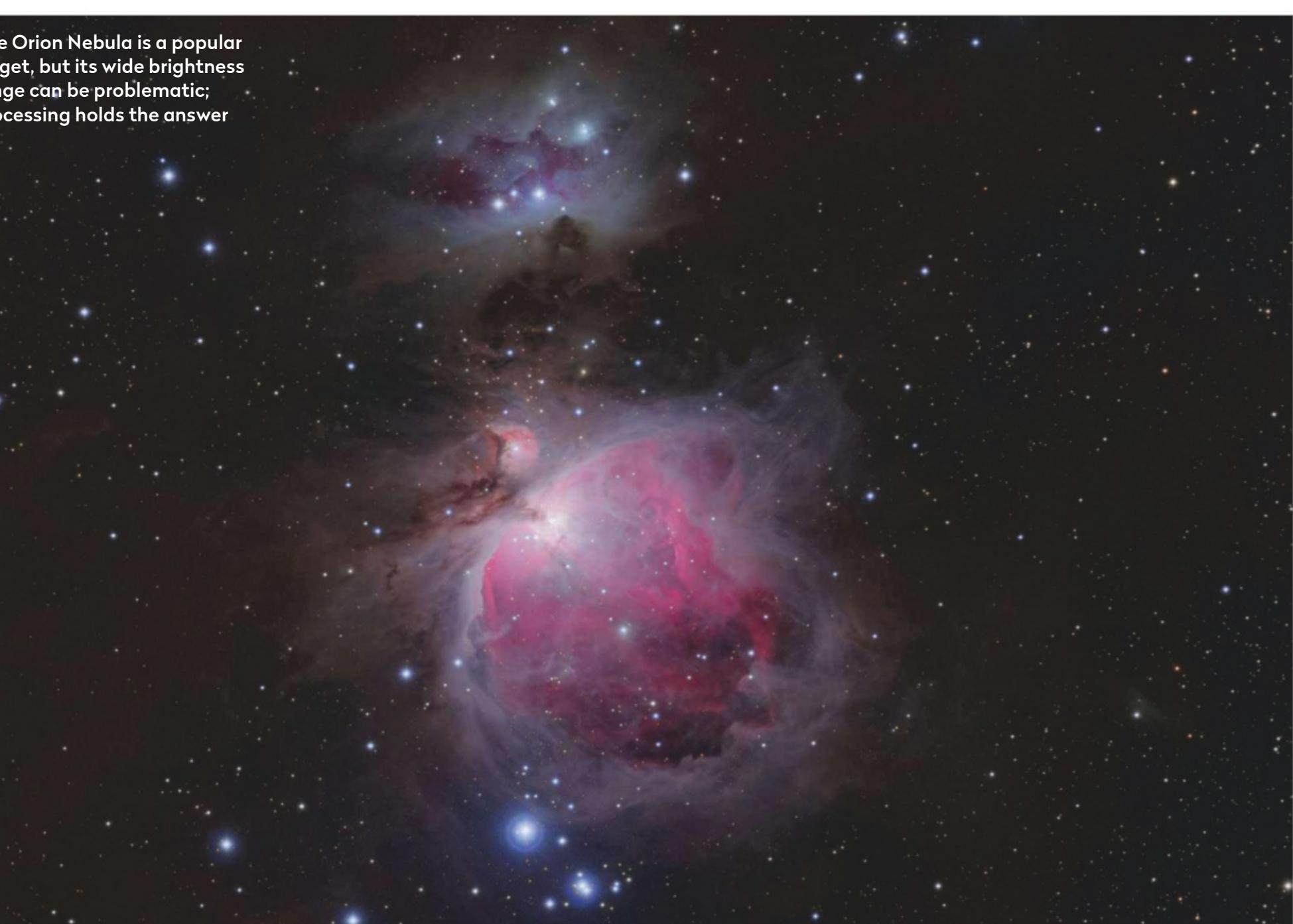
Output Options lets you select the output type, specify where to save it and the animation frame rate. Set this to 1fps or 2fps. For GIFs, tick the Loop Frames Repeatedly option.

6 Start processing

Select the Do Processing tab and click Start Processing. If everything is right, your output file will be generated, with PIPP automatically opening the folder that contains it when done.

DEEP-SKY OBJECTS BASIC TECHNIQUES

The Orion Nebula is a popular target, but its wide brightness range can be problematic; processing holds the answer



We're heading out of the Solar System now, and looking at the techniques used to edit photos of deep-sky objects. The toolkit needed for these celestial sights is subtly different, as the long exposures required for deep-sky imaging don't always make things easy.

Light pollution creates a colour cast that can turn your images a rather unpleasant shade of orange. Here, we'll be looking at the tools you can use to

reduce this unwanted effect, as well as describing ways to squeeze every last drop of detail out of your shots.

We'll also introduce some of the techniques used in colour imaging to help keep everything looking sharp and crisp, give you some shortcuts to keep your imaging time down and examine one of the most important elements of an image – its histogram. Understanding how a histogram works is the key to unlocking some of the hidden gems

that may be lurking in your images. Finally, we'll look at how layer masking can be used to join images taken with different exposures.

OUR EXPERT



Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

WHAT YOU'LL LEARN

97 Light pollution reduction

If streetlamps are adding orange to your images, use these tips to remove it

98 Image histograms

Histograms can be an astrophotographer's best friend. Learn all about them here

100 Colour handling

Discover the best ways to alter colour and how luminosity data can improve your images

102 Enhancing deep-sky objects

Learn how to save background stars and combine different exposures of the same target

LIGHT POLLUTION REDUCTION

Make light work of an artificial annoyance with software

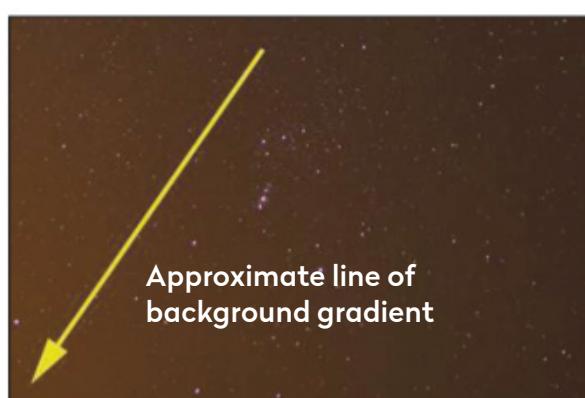


▲ Removing the glow caused by light pollution is a simple way of enhancing your images

The night sky is best seen in completely dark conditions, which are becoming a rarity for most of us. Street lighting, security lights and floodlights are just some of the sources of artificial illumination that rob the night of darkness. Take a long-exposure photo from most parts of the UK and the chances are that it will have an orange hue, caused by the light from streetlamps reflecting off particles in the atmosphere.

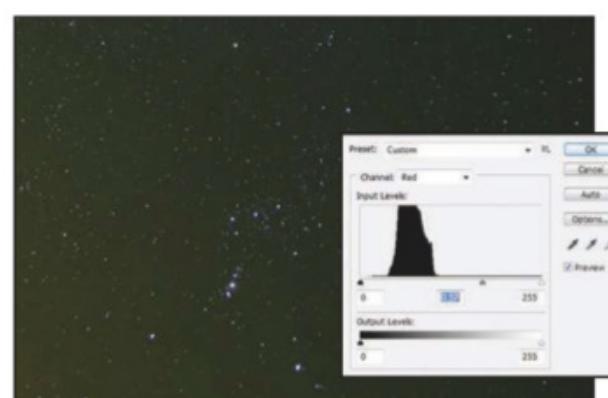
You can deal with light pollution at source: a mono CCD camera fitted with a narrowband filter, under certain lighting, can let you image without interference. Likewise, a DSLR fitted with a city light suppression (CLS) filter can also help. If you don't have filters, then you can turn to image processing, as shown below.

STEP BY STEP: Removing the effects of light pollution



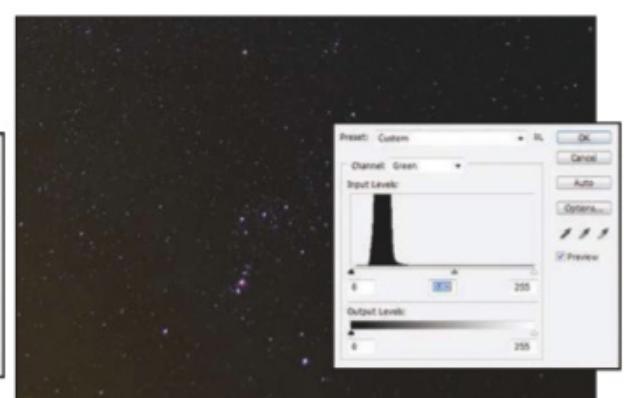
1 Orange and uneven

This image shows some of the typical characteristics associated with light pollution – an orange-brown discolouration and an uneven brightness gradient.



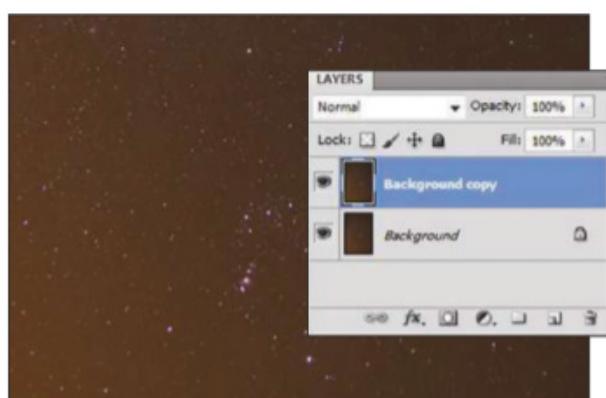
2 Drop the red...

If you're not bothered about the gradient, use the levels tool to drag the mid-point slider for the red channel to the right until the sky has a slight green tinge.



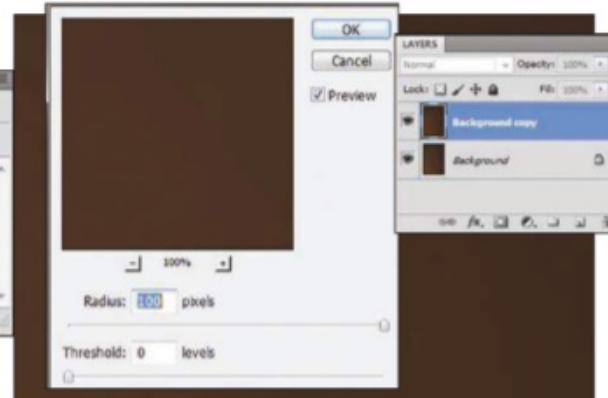
3 ...Then the green

Repeat the process with the green channel, this time dragging the mid-point slider to the right until the sky starts to look black with no significant red or green hue.



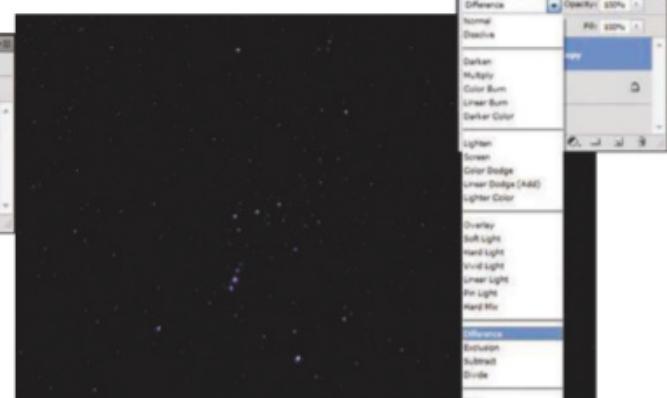
4 Duplicate layer

If your image has a significant gradient, open it in a layer-based editor and duplicate the main image so that you have two layers with the same image.



5 Scratch the stars away

Use the dust and scratches filter on the upper layer, setting the radius value to 100 and the threshold value to 0. Ideally all stars and features should disappear.



6 Blend

Change the blend mode of the layer with stars removed to difference. Use the curves tool to brighten or darken as needed, then merge with the main layer.

IMAGE HISTOGRAMS

A simple way of managing brightness, contrast and tones

Somewhere along the line of getting to grips with image processing, you're going to encounter histograms, which are very useful for getting the best out of your images.

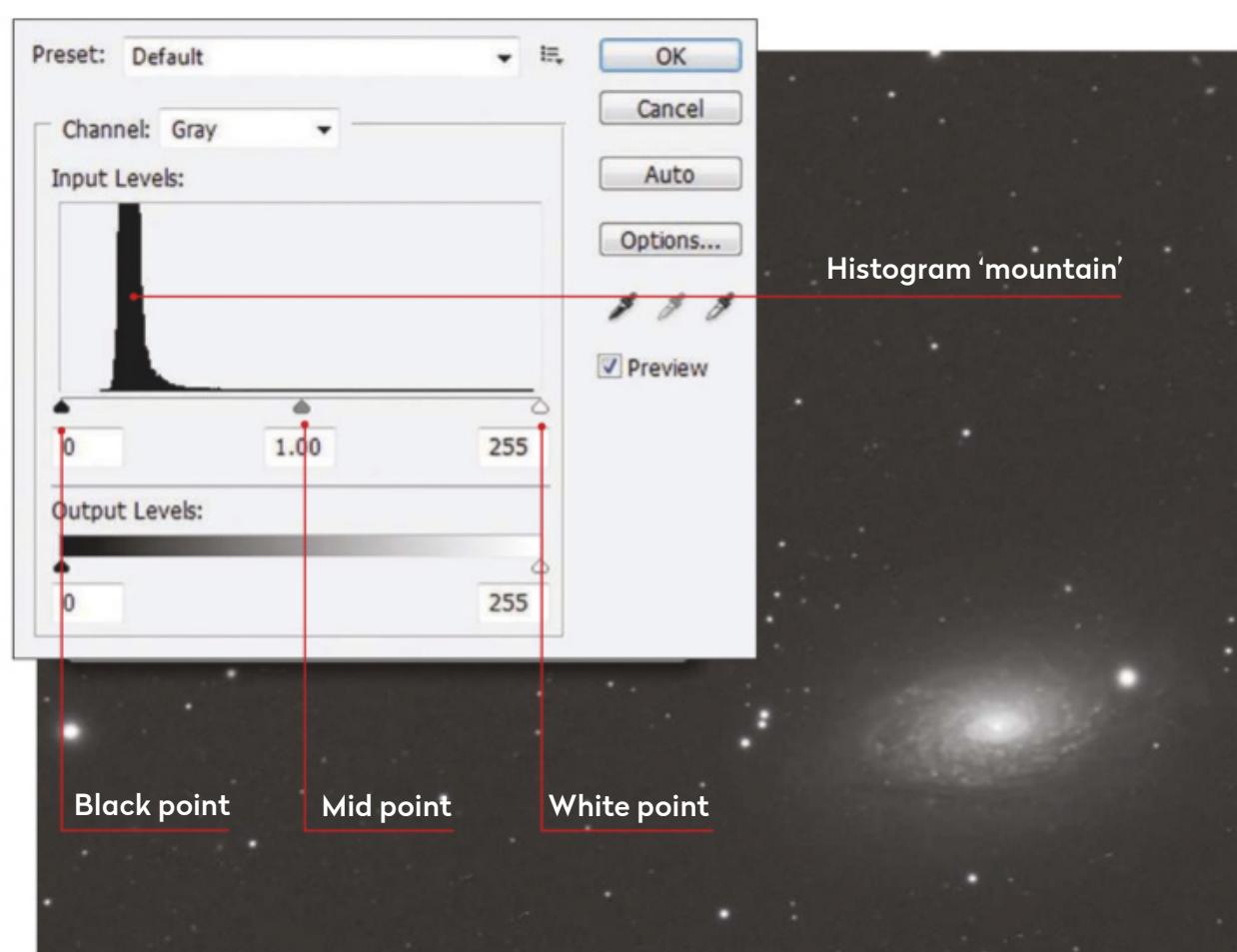
The histogram is a chart that shows how many pixels are in each of the shades or tones within an image. The tones are shown along a histogram's horizontal axis, with black typically on the left and white on the right. All of the intermediate values that can be recorded by your camera are arranged in order between these two extremes.

The number of pixels that each shade contains is shown on the histogram's vertical axis, with zero at the bottom. Each bar in the histogram represents a tone's pixel count. As there are normally many tonal values along the horizontal axis, the bars blend into one another to form a graph that resembles a mountain range. The absolute height value of the vertical bars – the pixel value counts – isn't that important. They simply show the relative abundance of one value compared to another.

The histogram also provides information about the image's content. Images of a lot of stars against a dark sky will typically show a large peak close to the black point of the histogram. This indicates that there are a lot of dark colours in the image. The number of

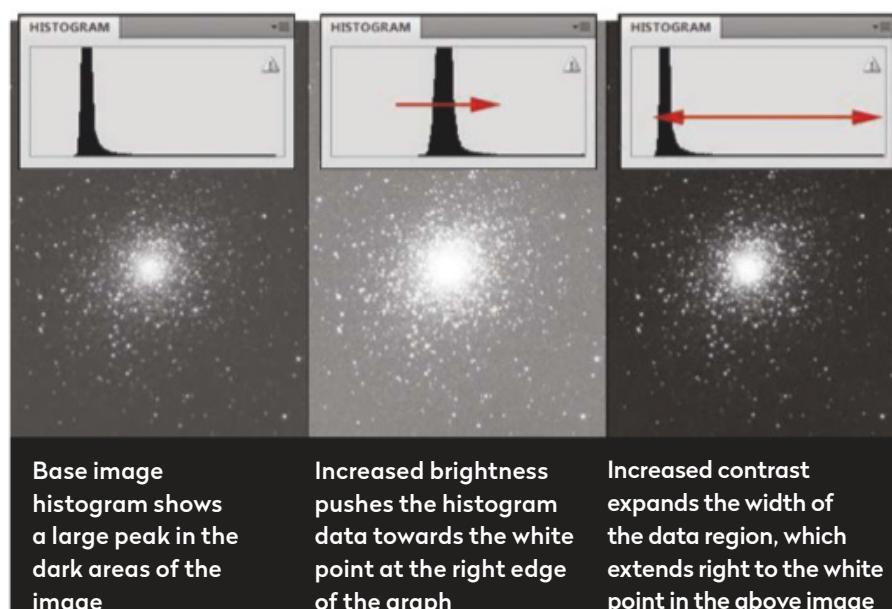
shades of grey your camera can represent is measured by its bit-depth: the higher the bit-depth, the greater the number of shades. So for a camera with a large bit-depth, typical of many CCD cameras, the number of shades that can be recorded will be measured in the thousands. It's not unusual for the pixels representing the subject in a CCD image

to be squashed towards the dark end of the histogram. Open such an image in a normal graphics editor and all you'll see are dark pixels. A process known as histogram stretching, detailed below, can help you to make the otherwise hidden part of the histogram visible, pulling what was originally in the dark back into the light.



▲ Histograms indicate the relative amounts of the tones in your image

BRIGHTNESS AND CONTRAST STRETCHING



Base image
histogram shows
a large peak in the
dark areas of the
image

Increased brightness
pushes the histogram
data towards the white
point at the right edge
of the graph

Increased contrast
expands the width of
the data region, which
extends right to the white
point in the above image

▲ Stretching can help bring objects lost in darkness back into view

Increasing the brightness of an image causes the histogram to shift towards the white point. Shifting too far causes the brighter pixels to reach the white point, where they become pure white. If pixels hit this point and the shift is accepted, the affected areas of the image will contain no recoverable data, just pure white pixels. Pushing part of the histogram off the end of the scale like this is called tone clipping.

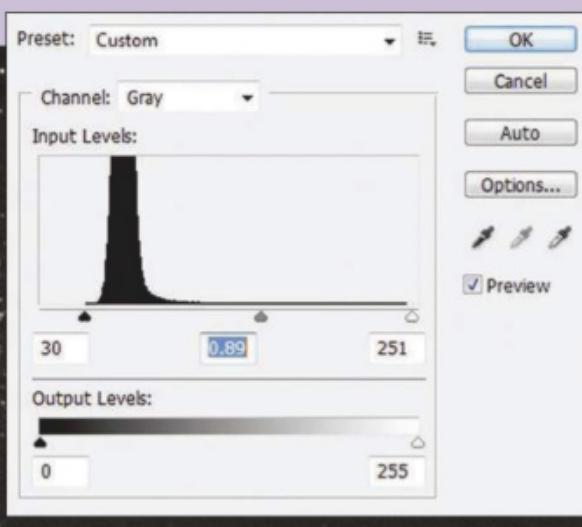
Similarly, decreasing the brightness of an image shifts the histogram towards the black point. Go too far and pixels that hit the edge become totally black. In deep-sky images a pure black background sky can look unnatural, so it's important to avoid clipping the black point.

The distribution of tones in an image – that is, the width of the significant 'mountain' region in the histogram – defines the overall image contrast. For an image with poor contrast, the histogram data is compressed into a narrow peak. Adjusting the contrast allows you to vary the width of the peak.

LEVELS



▲ The levels tool allows you to brighten or darken whole images



The levels adjustment tool works directly on an image's histogram data, allowing you to adjust the black, white and midtone points for the image. In the main display of the levels window is the histogram itself. Looking carefully at it can reveal issues with your image that need to be addressed.

Ideally, the black point should be just before the histogram begins to rise above horizontal axis. Similarly, the white point should be just after the histogram becomes flat again. This gives the image maximum contrast.

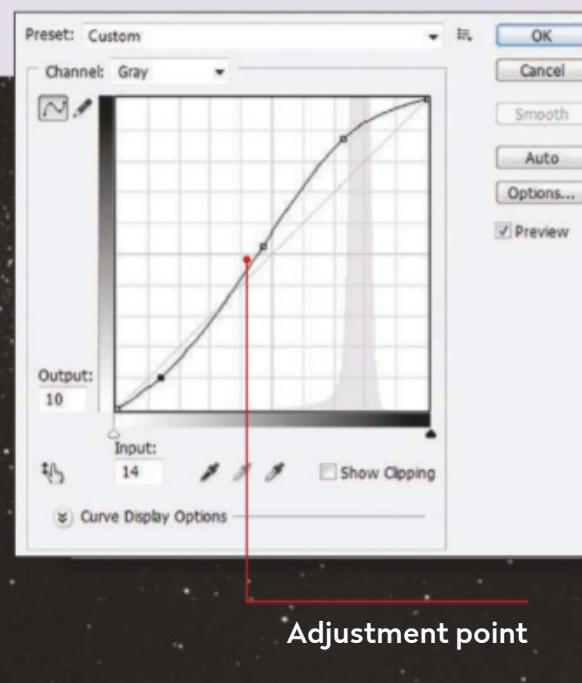
The position of the mid-point slider redefines the image's mid-grey point, allowing you to brighten or darken your shot without introducing any tone clipping, provided you keep it between the black and white points.

Levels adjustments are useful for bringing out faint detail in an image, but the tool does have its limitations due to it being a linear adjustment. This means that, unless you use advanced techniques, it's not possible to address one set of tones while leaving the others untouched.

CURVES



▲ Use the curves tool to target specific tones within your image

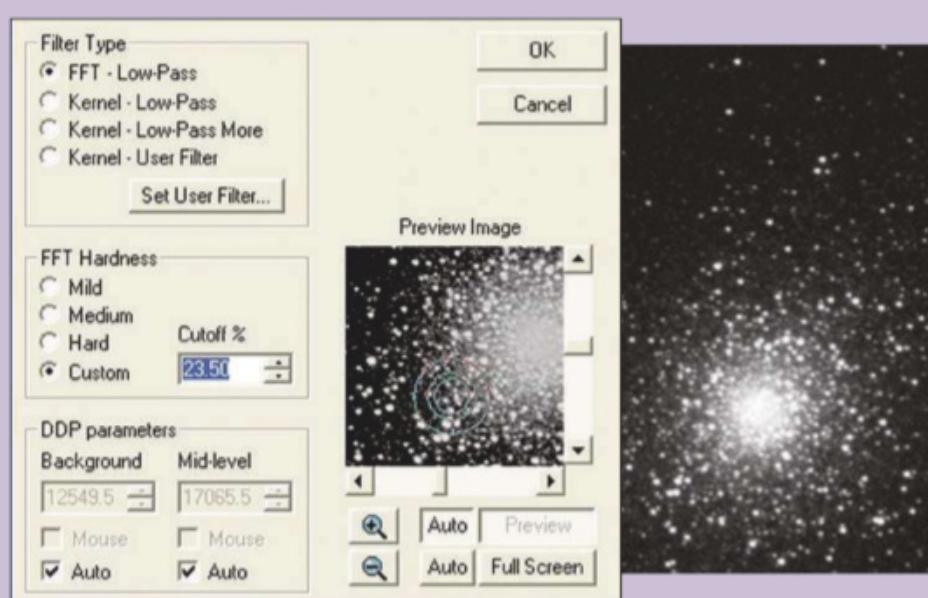


The curves tool is a more flexible version of the levels tool. Unlike the single mid-grey slider of levels, curves offers 256 adjustment points – one for every tone of an 8-bit image channel – allowing for a form of non-linear stretching. Careful use of this tool can allow you to target specific tonal regions in an image, mapping them to a brighter or dimmer range.

Making adjustments using the curves tool is easy. You'll typically start with the curve represented as a straight line at a 45° angle. In most cases, the horizontal axis shows the tone being adjusted, while the vertical axis shows where the original tones will end up, as defined by the shape of the curve. The default 45° 'curve' indicates that each original tone maps onto an identical value. By dragging this line out of shape, you're redefining this mapping. Make adjustments by adding points to the adjustment curve and dragging these points using your mouse.

Ideally the adjustment curve should flow smoothly. Try and avoid pushing any part of it up against the edge of the adjustment area as this will introduce tone clipping.

DIGITAL DEVELOPMENT



▲ DDP routines can enhance faint objects without altering bright ones

The process of pulling an image out of the data you've managed to capture is comparable to developing a photograph from a roll of film. The term Digital Development Processing (DDP) is used to describe this technique. One very important part of DDP is non-linear histogram stretching.

DDP is a tool that is often found in dedicated astronomical image processing packages. It's used to stretch parts of an image histogram in a way that artificially emphasises certain elements while leaving the others largely untouched. This is useful if, for example, you want to pull out the faint, wispy parts of a galaxy or nebula while maintaining the overall appearance of the normally bright regions.

There are various implementations of DDP across different image processing packages. In MaxIm DL, pictured left, DDP performs a combination of unsharp masking and gamma stretching. The latter allows you to emphasise bright or dim regions in your image.

COLOUR HANDLING

How to save time when imaging in monochrome

A variety of cameras are suitable for deep-sky imaging, ranging from DSLRs to specialised astronomical CCD cameras that are cooled to minimise image noise. While both types of camera are available as one-shot colour devices, it's more desirable to have a monochrome astronomical CCD camera. This is despite the fact that it's more time-consuming to produce colour results this way, since you'll need to take several images through single-colour filters.

One advantage of this approach is that you can separate an image's colour data from its spatial detail information. Once this has been done, different emphasis can be placed on these two elements.

Spatial detail is defined by an image's luminosity, which can be collected separately by using a luminosity (L) filter. Colour information, captured using red, green and blue (RGB) filters, is less important and doesn't contribute significantly to the quality of detail in an image. This may sound rather odd, but as long as you have an excellent luminosity image, the colour component can even be blurred without seriously affecting the end result.

To capture luminosity with a CCD camera, you need to set it to its highest resolution – this ensures that you get the finest quality image possible. To



achieve the same depth of image from the RGB-filtered shots you should ideally triple the exposure length you used for the L-filtered shots. This is because each RGB filter only lets in a third of the incoming light as the L filter.

But because colour resolution isn't too important, you can use CCD binning to up your camera's sensitivity, giving shorter exposures at the expense of

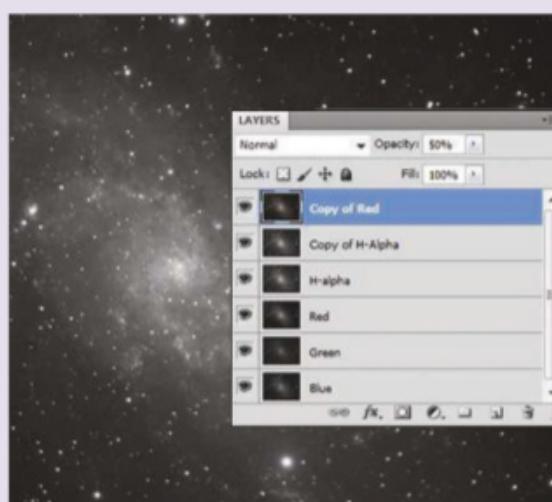
resolution. Set your camera in 3x3 binning mode and each 3x3 grid of photosites will behave as one 'super-pixel'. The sensor acts as if it's nine times more sensitive but with one-ninth of the resolution. With binned colour exposures just a third as long as L exposures, you'll get exactly the colour information you need – RGB exposures that are three times as long as your L exposures.

ALL PICTURES: PETE LAWRENCE

COLOUR ADJUSTMENT TECHNIQUES

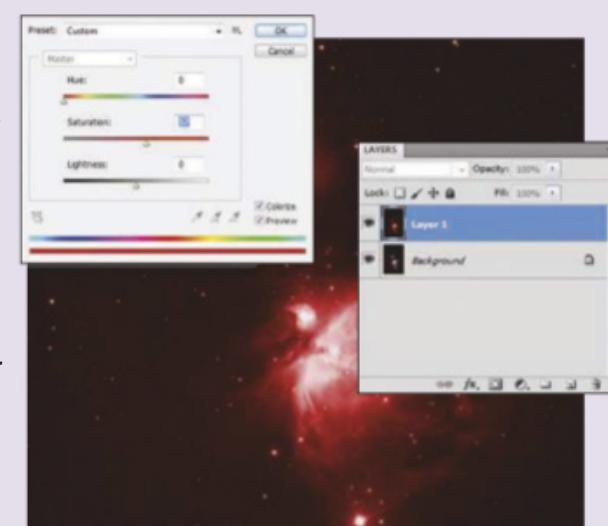
Adding hydrogen-alpha information

To add a hydrogen-alpha (Ha) image to an RGB image, open the Ha image and add an R image as a layer on top. Set the R transparency to 30-50 per cent, then flatten. Build a new LRGB image (see page 101) replacing R and L with the new HaR image.

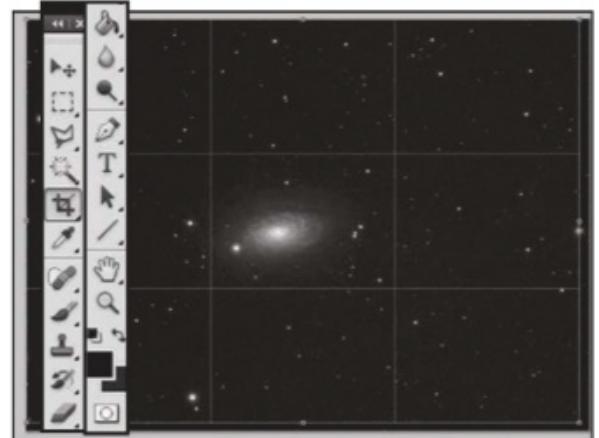
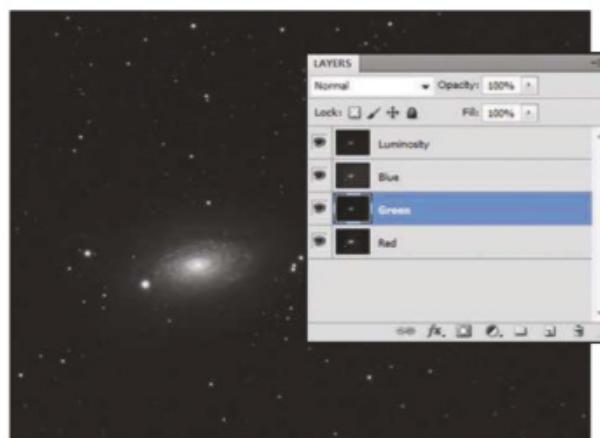
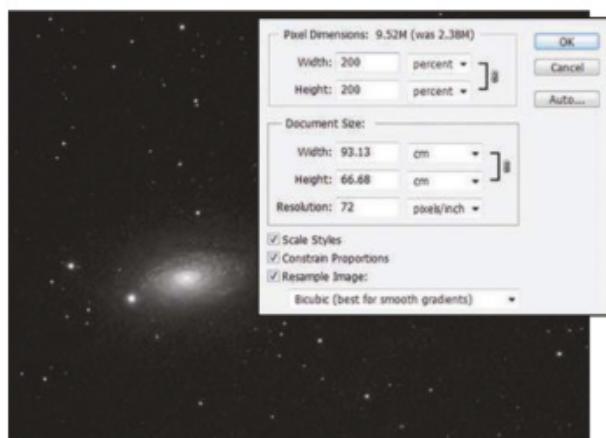


Red colour enhancement

Open an RGB image, then copy and paste the R channel as a new layer. False colour the R layer with the hue/saturation control – tick colourise, then set hue to 0 and saturation to 50-70 per cent. Set the upper blend mode to lighten and adjust layer transparency to taste.



STEP BY STEP: Add luminance data to CCD camera RGB images



1 Expand binned images

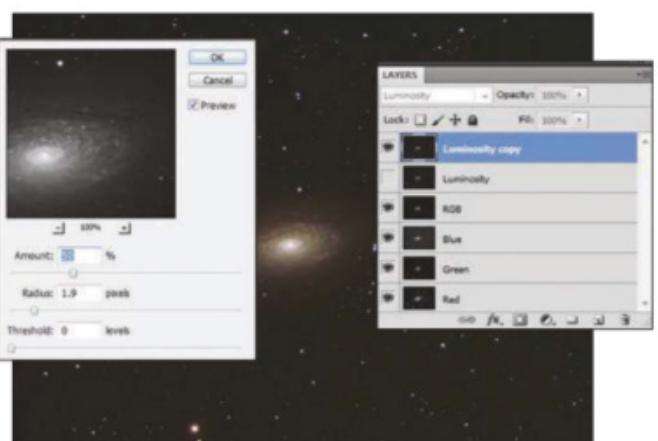
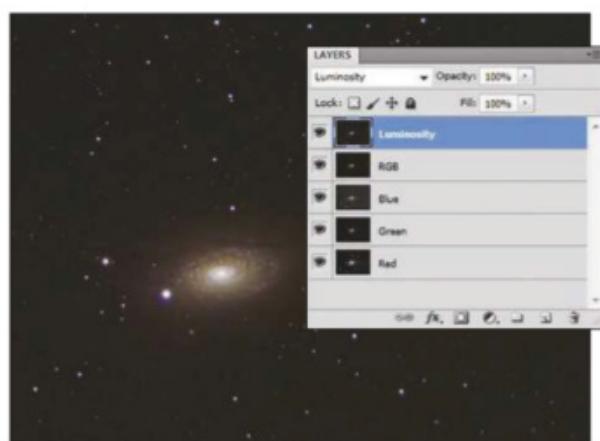
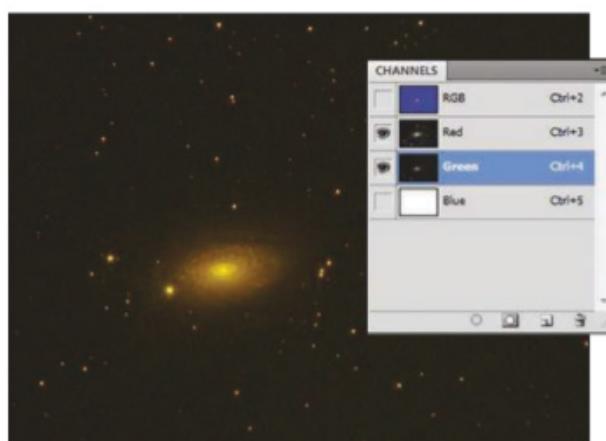
We'll assume you've calibrated L, R, G and B images. If you've used binning to capture the RGB images, you'll need to increase their size so to match the L image. If you used 2x2 binning, increase them by 200 per cent; if you used 3x3 binning, increase them by 300 per cent.

2 Align layers

In your graphics editor, create a blank RGB image the same size as your L image and load the R, G, B and L images as separate layers. Keep the bottom layer visible and hide all but one of the others. Nudge this layer so that its contents align with the bottom layer.

3 Prepare to assemble

Repeat for the remaining layers, hiding the ones that are not being aligned as you go. Finally, look for any gaps that may have appeared at the edge of any of the layers and crop the entire image so that these are removed. The four layers are now ready to be assembled.



4 Duplicate

Create another blank RGB image and call it '#2'. Copy and paste the R image into #2's red channel, then copy the G and B images into their own channels. With all channels active, select the full-colour RGB image and copy it back into the original image as a new layer. Discard #2.

5 Luminance on top

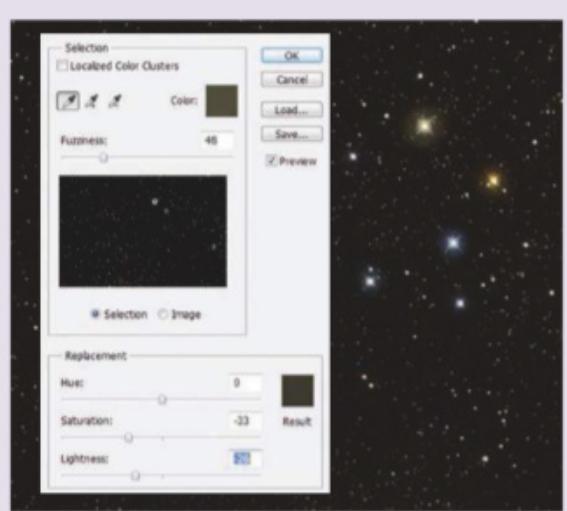
Move the L layer above the RGB layer. Set the blend mode of the L layer to luminosity. Adjust the saturation, levels and curves of the RGB layer to produce a natural-looking image. If the RGB layer is noisy, a weak Gaussian blur can be added with little effect on the end result.

6 Adjust and sharpen

The L layer can also be adjusted using levels and curves. Sharpening it may also enhance the end result. What's important is to keep the quality of this layer as high as possible and, for this reason, it's a good idea to duplicate the L layer, keeping the hidden original as a backup.

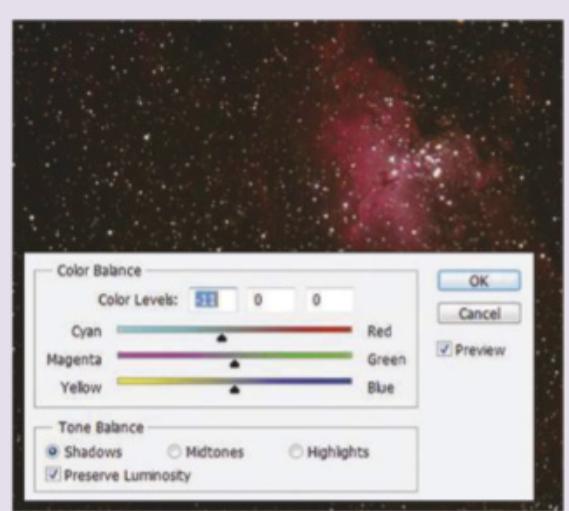
Colour replacement

The replace colour tool can be used to fix problems, such as blue haloes around stars. Sample the halo with the dropper, then increase fuzziness until you've got the problem area. Reduce the saturation, then the lightness. Keep adjusting these until the haloes vanish.



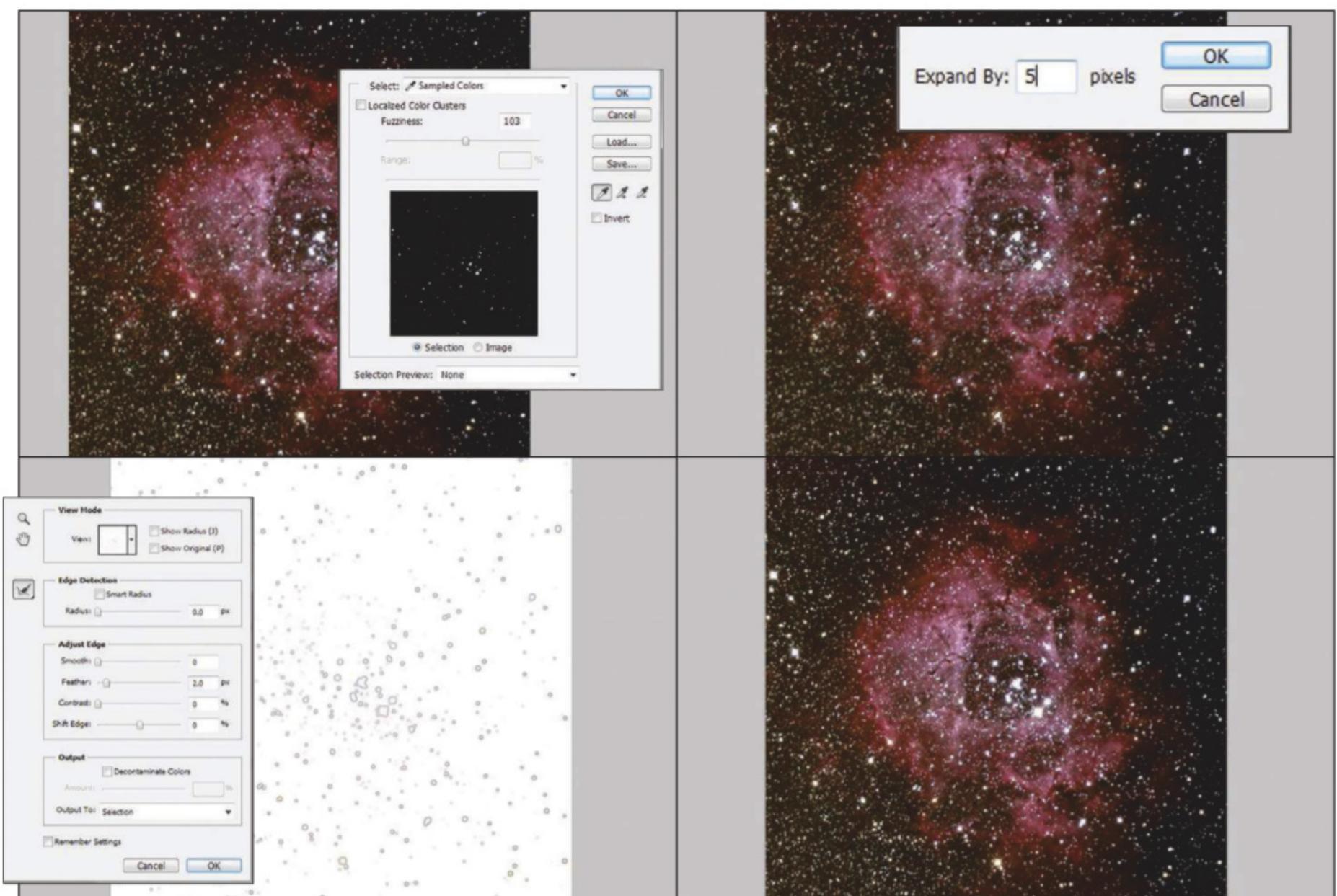
Adjusting overall colour balance

The colour balance tool can be used to adjust an image's overall colour. The tool works on three tonal regions of an image – shadows, midtones and highlights. If your image has a dark background colour cast, select shadows and adjust the colour sliders as necessary.



ENHANCING DEEP-SKY OBJECTS

Process nebulae and clusters without washing out stars



▲ Selecting every star in an image sounds laborious but is quite easy; once mastered, it lets you bring colour back to overexposed stars

A typical deep-sky photograph will contain stars as well as the deep-sky object itself. Of course, in the case of an open cluster or double cluster shot, your picture is more than likely to contain nothing but stars!

But stars present something of a problem when it comes to manipulating photographs because of the way they appear in an image. A star is a point source of light, but Earth's atmosphere wobbles this point source so that it looks like a small disc on a long-exposure image. The disc's diameter is proportional to the star's brightness and its edge is likely to be well defined but not completely sharp.

The difficulty comes when you want to apply a process to a deep-sky object such as a nebula or a galaxy, but you don't want to alter the appearance of the stars around it. Unsharp masking, a common way of sharpening detail in an image,

works by increasing the contrast between light and dark regions. Unfortunately, it's also prone to creating dark rings around stars – overuse can make the stars appear too abrupt around their edges.

One way around this is to select the stars, then invert the selection to protect them from editing. If the thought of selecting every star in an image sounds daunting, don't worry. It's not as hard as it sounds and there are several ways to do it. One of the simplest methods involves using a colour range selection tool (you find this in Photoshop by clicking on Select > Colour Range) and sampling the star colour at the centre of a bright star, which should be white. Altering the fuzziness of the selection so that stars alone are selected is normally sufficient to get most of them.

Once done, expand the selection (in Photoshop: Select > Modify > Expand) by between two and five pixels, then

soften the hard selection edge by two pixels using feather (in Photoshop: Select > Refine Edge > Feather). Inverting the selection allows you to apply a gentle unsharp mask to the deep-sky object without affecting the stars.

Once the stars have been selected, a whole world of additional possibilities comes into view. As an example, most star images are overexposed, causing their centres to appear white. Look carefully, though, and around the edge of the white disc will be a ring of coloured pixels – the recorded colour of the star.

By duplicating the base layer and selecting the stars as described above, it's possible to blur the upper layer so the colour ring spreads into the centre of the star. Setting the upper layer's blend mode to colour and its saturation to high will then reintroduce some of this missing colour. Make sure the selection is still actively set on the stars as you do this.

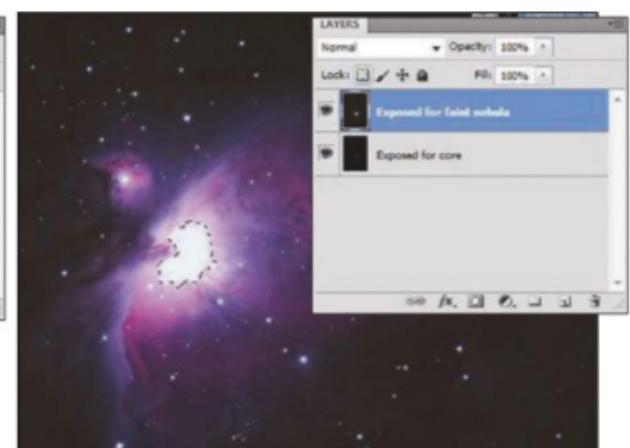
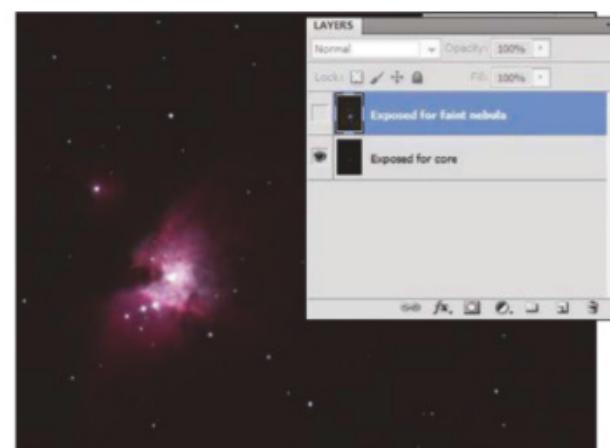
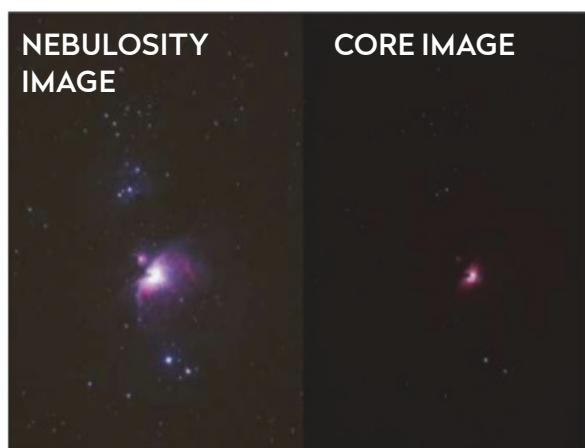
LAYER MASKING

How layer masking can improve the look of deep-sky objects

You've just learned how to select or deselect the stars in an image, but what if there are parts of the object itself that need special treatment? A good example is the fabulous Orion Nebula, a deep-sky object that exhibits a wide brightness range from its core to its outer regions. If you expose for the core, not much of the outer nebulosity will appear. Conversely, expose for the faint outer wisps and you'll overexpose the core. One way to tackle this is to take two exposures, one optimised for the faint stuff, the other optimised for the core and join them using layer masking. Successfully applying this technique will result in a seamless blend between the otherwise completely mismatched exposures, allowing you to concentrate on bringing out the best from both.



STEP BY STEP: Layer masking the Orion Nebula



1 Take two

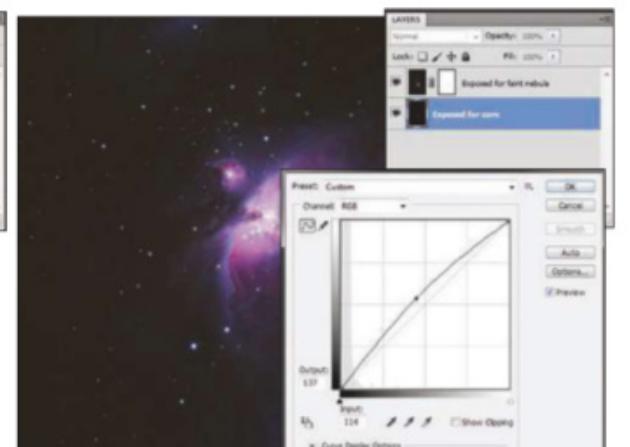
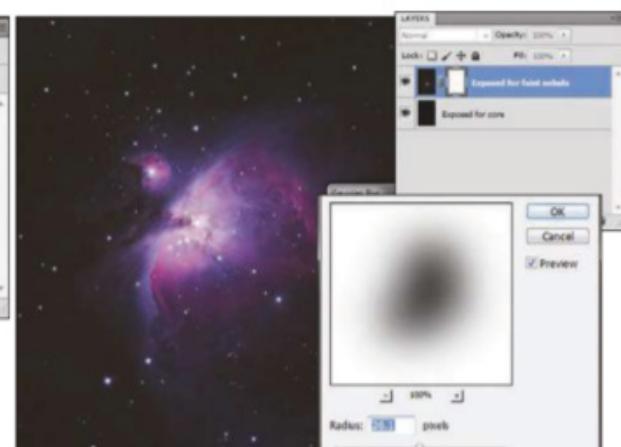
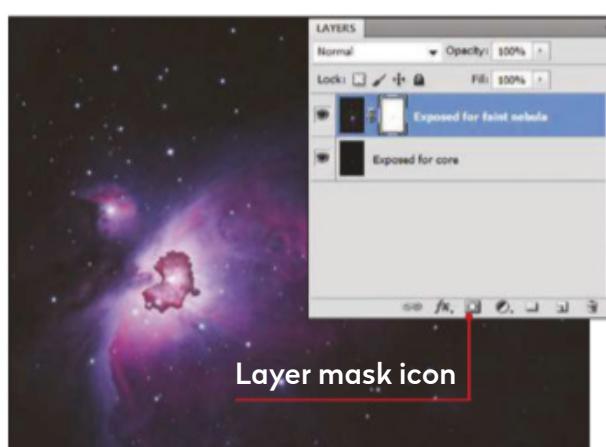
We'll assume you have two images, one exposed for the core and the other exposed for the outer parts of the nebula. Copy and paste one into the other as a separate layer.

2 Faint bits on top

Ensure the image for the faint regions is the upper layer, then nudge and rotate it until the stars no longer shift position when you toggle visibility. At this point, the images are aligned.

3 Select the core

Select the overexposed core in the upper layer. You don't have to be too precise here: just select the entire area almost, but not quite, to the edge of the overexposed region.



4 Create a layer mask

Create a layer mask for the upper layer. In Photoshop, you can do this by clicking on the layer mask icon while holding down the alt key.

5 Select mask

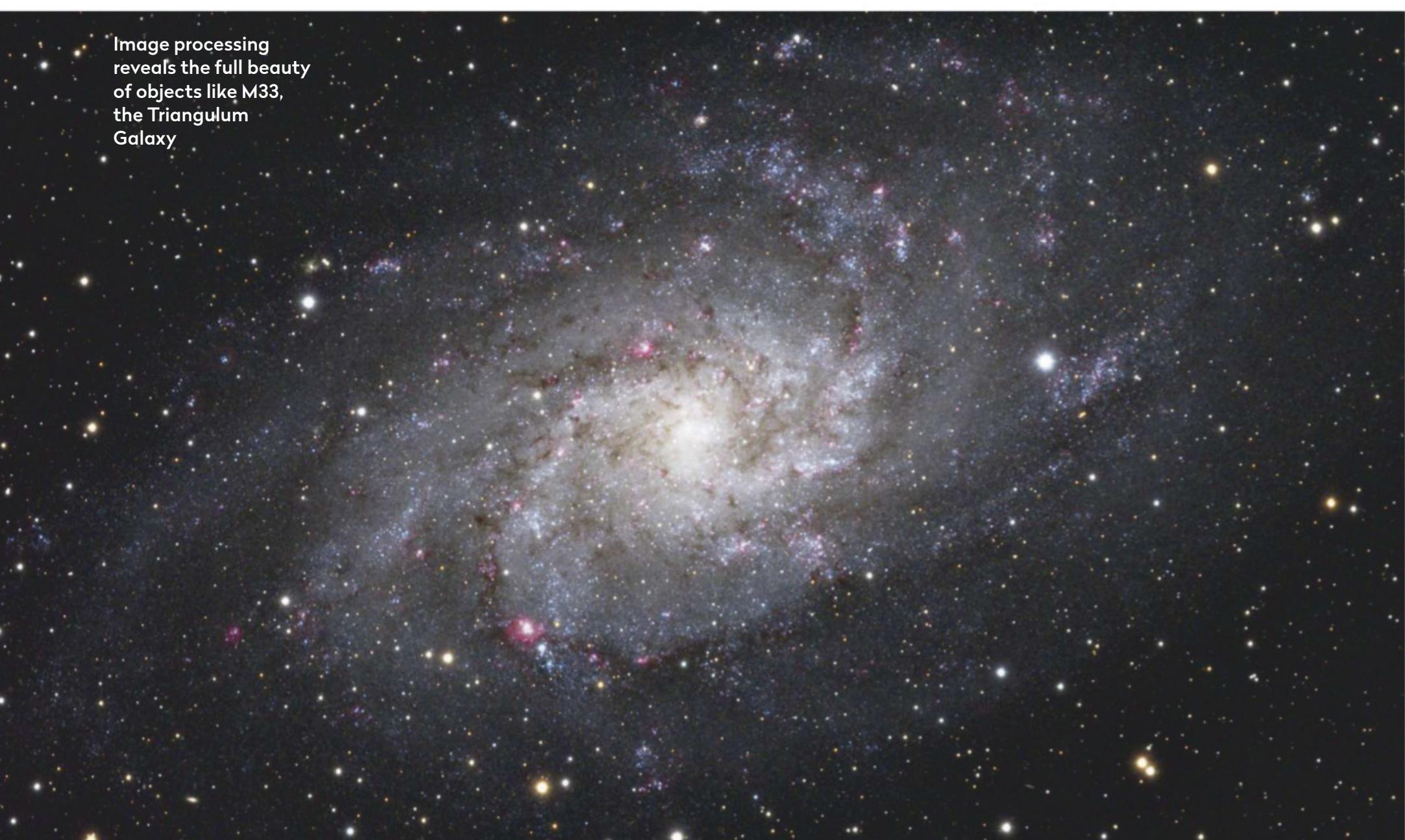
Select the new mask by clicking on it in the layers display. Apply a fairly strong Gaussian blur to make the core's mask appear fuzzy with soft edges.

6 Blend

Click on the image preview in the layers display, then blend the two images using the levels and curves tools until the overall effect looks natural.

DEEP-SKY OBJECTS ADVANCED TECHNIQUES

Image processing reveals the full beauty of objects like M33, the Triangulum Galaxy



For this concluding section we're going to introduce some advanced techniques to help you edit your deep-sky shots. First up, we'll be investigating some smart ways to coax more vibrant colours and detail out of your images using a process known as multiple luminance layering. We'll also be focusing on stars, as they're a reliable indicator of how good your optics, mount and processing techniques are. If any of these aren't quite right, the shape of the stars in your images will give the game

away. Fortunately, there are several techniques that can be used to recover poorly shaped stars.

Despite the many positive aspects of digital imaging devices, noise can still be a major problem, so we'll also be taking a look at image calibration. The term calibration describes a suite of techniques that reduce the damage caused by the different kinds of optical and digital noise.

We'll round things off by looking at comet processing and narrowband

imaging – the latter really can lend new depth to your images of familiar deep-sky objects, revealing aspects in them that you perhaps never even knew existed.

OUR EXPERT



Pete Lawrence is an astrophotography expert and presenter of *The Sky at Night*

WHAT YOU'LL LEARN

105 Multiple luminance layers

Why settle for one layer of detail? Extra luminance data means extra clarity

106 Image calibration

How to counter noise, the 'stuff' that appears in astro images that shouldn't be there

108 Star processing

Prevent stars from becoming fuzzy discs and enhance their natural colours

110 Narrowband imaging

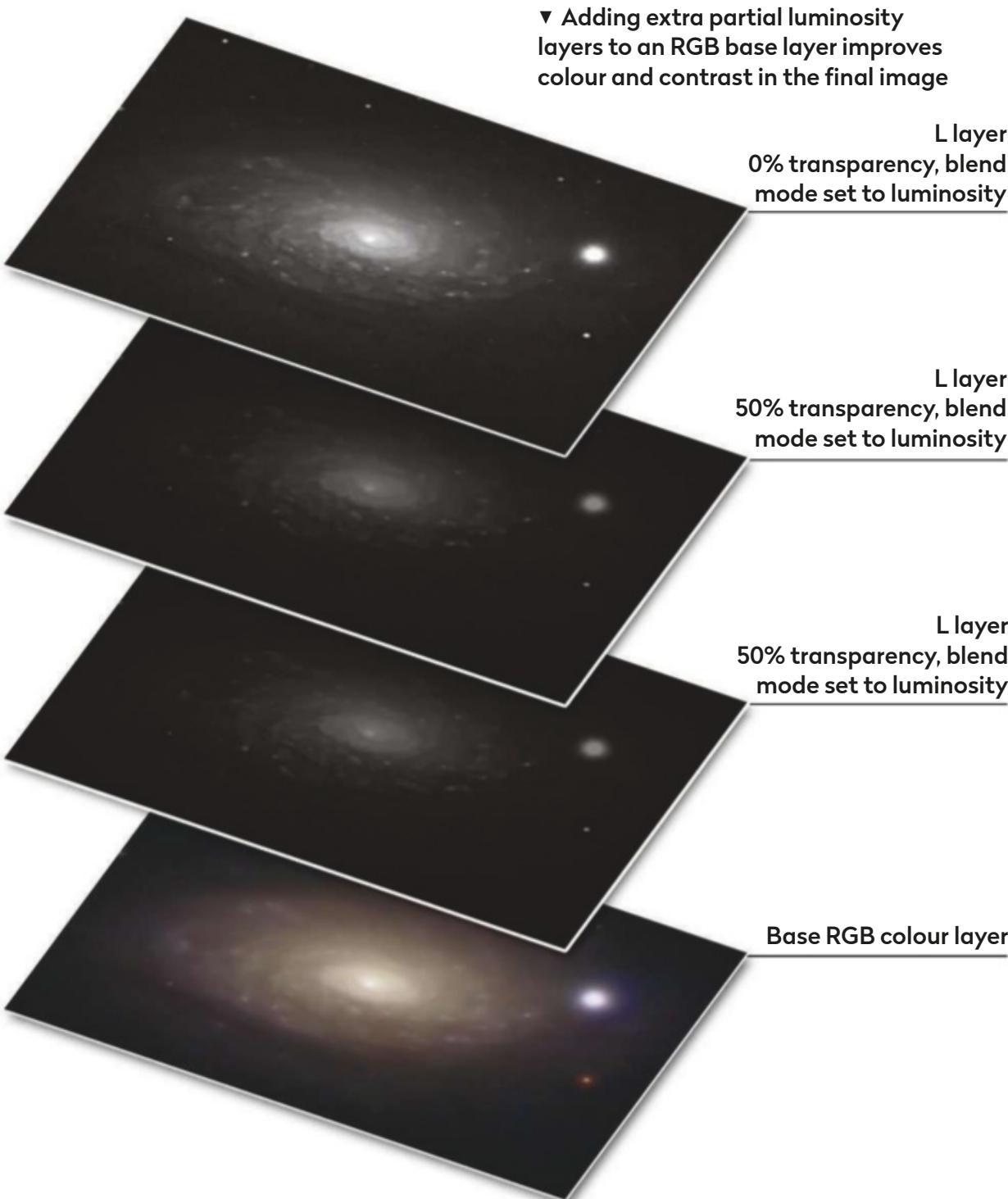
See the night sky in a new light by filtering out everything but specific wavelengths

111 Comet processing

Blend images of a comet and its star field to get an image that shows both sharply

MULTIPLE LUMINANCE LAYERS

A bright idea that adds depth to muted images



The visual components of an image can be broken down into colour and luminosity information.

Luminosity is the most important aspect to get right as it provides all the detail in the image. If you're using a monochrome camera and filters, the colour element is normally captured using red (R), green (G) and blue (B) filters, then combined with a separate luminosity (L) shot to create a LRGB image.

RGB-filtered shots are combined by adding them into the respective colour channels of an initially blank RGB image. This forms a base colour layer for the image. The L-filtered shot is then added as a separate layer above the base colour layer, with its blend mode set to luminosity. To look at, an L filter is typically clear, but it blocks infrared and ultraviolet light.

One problem with this way of working is that the colour result can look muted compared with the crisp luminance layer, especially if the colour and luminance exposures are mismatched. While the final result can often work out fine for a basic LRGB shot, improvements can be made by creating a higher quality RGB base layer. One way to boost the colour layer is to increase its saturation, but this can also result in higher noise levels.

An advanced technique, pioneered by expert imager Rob Gendler, is to create a partial LRGB image using a 50 per cent transparent L layer, which is then flattened and saved. This file is then used as a replacement to the normal RGB colour base. The image is built as normal: you place the L layer above the base LRGB layer and set its blend mode to luminosity. This leaves you with an LLLRGB image. The double use of luminance information in this way provides greater colour saturation and resolution than a simple LRGB image on its own.

You don't have to stop there, however; the routine can be reapplied, if necessary, by using more luminance layers as shown to the left. Here, we've created an LLLRGB image. Saturation will continue to be enhanced using this technique, producing a deep-sky image that is colourful and rich in high-contrast detail.

IMAGE CALIBRATION

How to take the counter-intuitive shots that counter noise

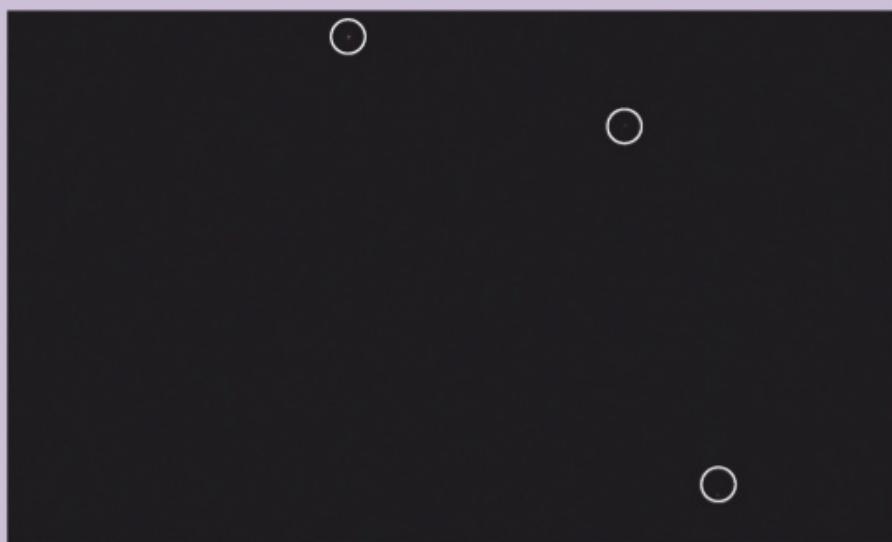
Despite its many benefits, the Achilles heel of digital imaging is noise. This manifests in several ways, but in essence noise is 'stuff' in your images that shouldn't be there. Most of it comes from the characteristics of the

imaging sensor, but other unwanted effects stem from elsewhere – the optics, for example. You can reduce the impact of this 'stuff' through calibration, taking calibration frames and applying them to your light frames using mathematical

processes. Programs like DeepSkyStacker can do this automatically. The term 'light frames' refers to normal images. This name helps to differentiate them from calibration images, such as the 'dark frames' that are explained below.

DARK FRAMES

Get rid of static noise



Static noise appears as specks that are fixed in place. It can be removed by taking a dark frame (a shot taken with the lens cap on) and subtracting this from the normal shot. Static noise is dependent on sensor temperature and exposure length, so take the dark frame during your imaging session, with the same exposure and ISO settings. Dark frames also contain random noise so several darks should be averaged to create a master.

STACKING

Get rid of random noise



Random noise occurs when heat creates a background charge in an imaging sensor. Stretching an image will also reveal random noise. Its effects can be reduced by averaging a number of shots taken at the same exposure and ISO settings, known as stacking. The more frames you stack, the smoother the result. The noise reduction can be calculated by dividing one by the square root of the number of frames stacked.

FLAT FRAMES

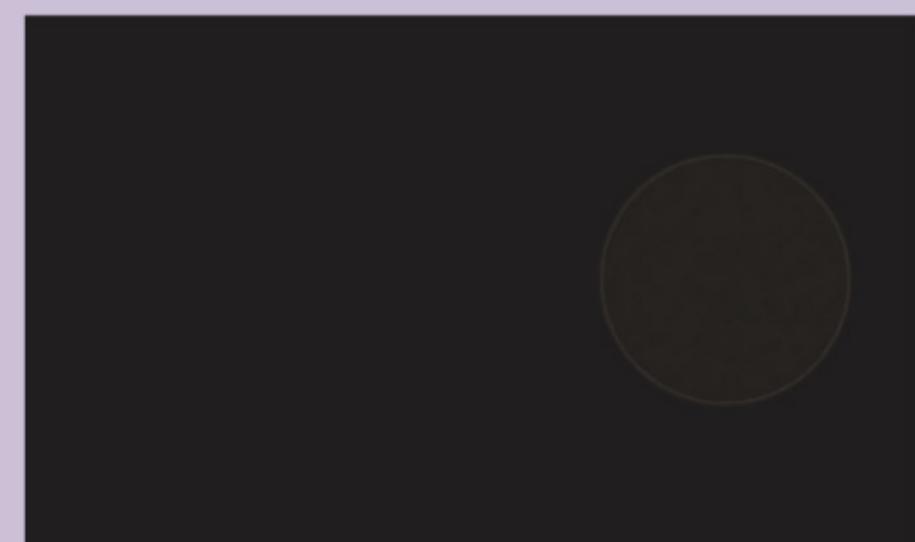
Get rid of optical issues



Optical issues caused by dust or incoming light being clipped by telescope components can be resolved with flat frames. Keep the camera focus and orientation fixed after you've taken your light frames, then point the scope at an evenly illuminated surface. A good flat shot should show a histogram peak that is 50-75 per cent saturated. Take a number of flats using the camera's lowest ISO setting and average them into a master.

OTHER FRAMES

Get rid of hot pixels and more



Bias frames (above), like dark frames, are taken with the lens cap on, but with the camera set to its shortest exposure. Bias frames identify and correct for pixels that don't reset to zero at the start of a new exposure. Flat dark frames are shots taken immediately after the flat field images using the same exposure and ISO settings, but with the lens cap in place. These are averaged together and used to calibrate the flats prior to applying them.

STEP BY STEP: Use DeepSkyStacker to apply calibration frames



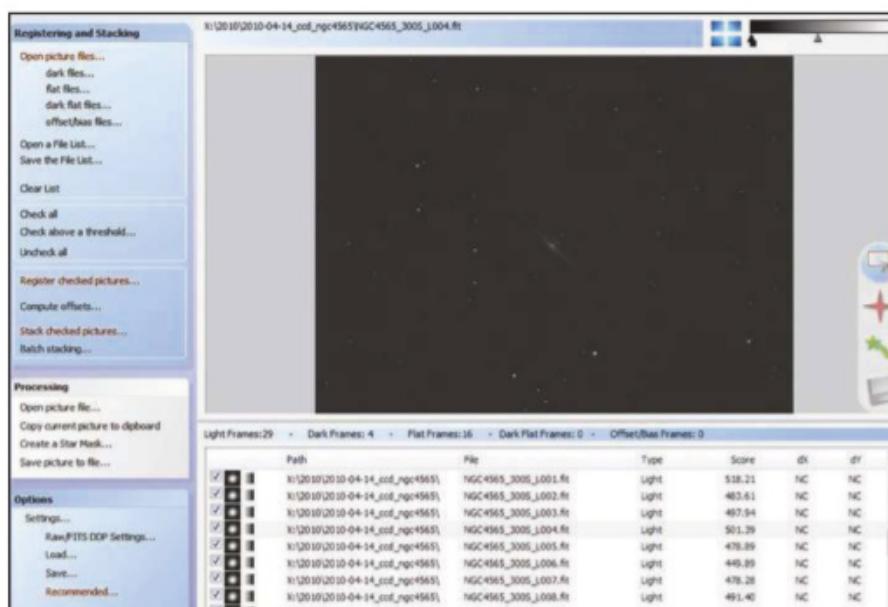
1 Load files

Load your light and calibration frames into DeepSky Stacker, clicking on the relevant option under Open picture files. When you have enough files to work with, name them according to what they contain as you capture them. Once loaded, the program applies the calibration frames automatically.

Path	File
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1001
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1002
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1003
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1004
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1005
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1006
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1007
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1008
C:\Temp\coathanger\2010-04-14_cc...	FLAT-L-1x1009

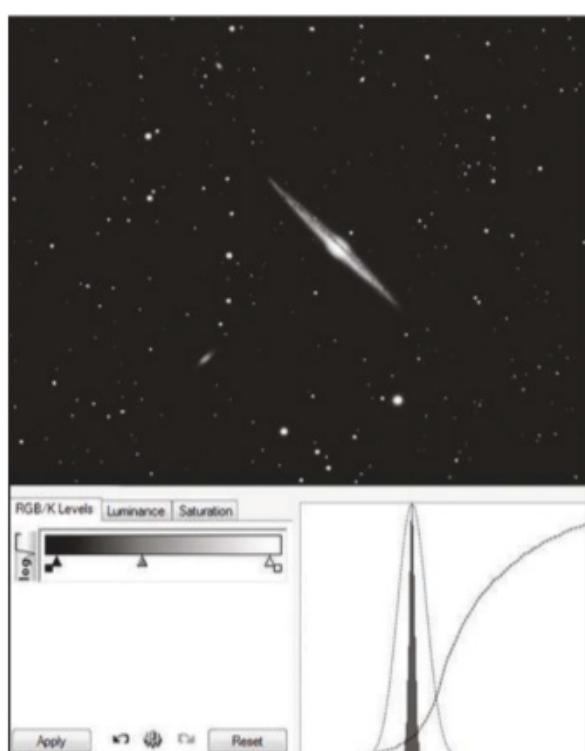
2 Create groups

You can combine images captured over several nights by loading the files from each night into separate groups. Bias frames should be loaded into your main group.



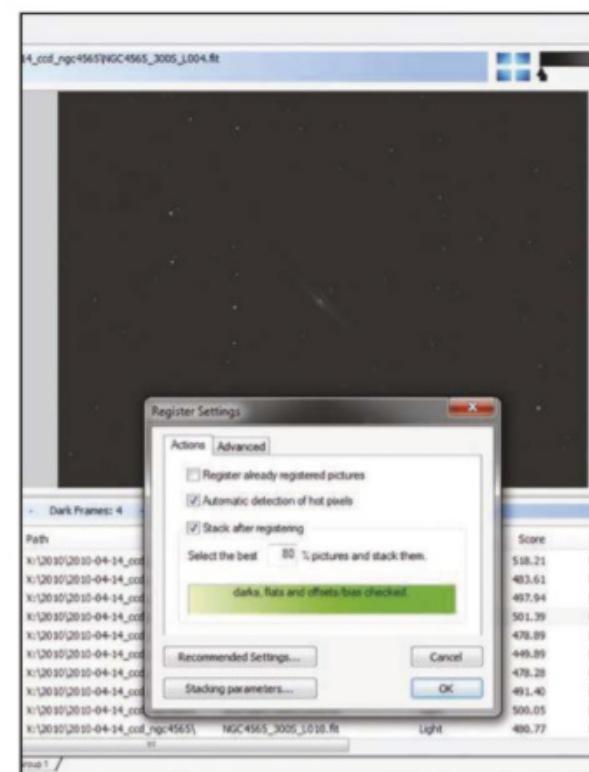
3 Review lights

Review the light frames by selecting each in turn and viewing its content. If necessary, use the tool in the upper-right corner to brighten the preview. This doesn't affect the file's content.



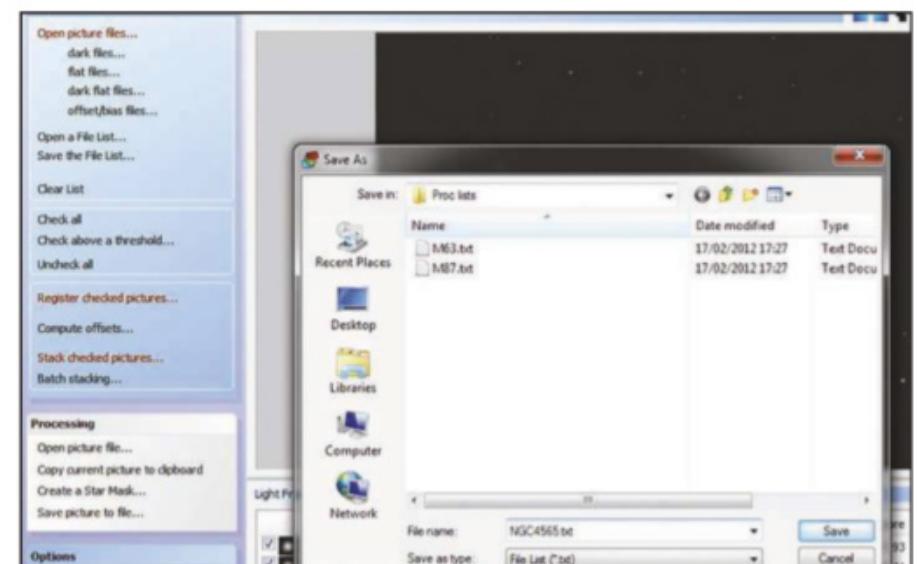
5 Align

Click on Stacking mode and select Standard, then click on Alignment method and select Automatic. Finally, hit OK and let DeepSkyStacker build the image. When complete, you'll be shown a final image that can be tweaked using the built-in tools. Once done, click on Save picture to file and save the result.



4 Tick, tick, tick

Tick each file you want to use in the final process. If you want to use all of them, click on Check all in the left-hand menu. Click on Register checked pictures, then tick the Automatic detection of hot pixels and Stack after registering boxes. Click on OK. A summary will appear along with further options.



6 Batch process

To process a lot of capture sessions, save the loaded file list via Save the File List. When done, click Batch stacking and load all your lists. They can then be batch-processed automatically.

STAR PROCESSING TECHNIQUES

Four effective ways of sharpening your star shapes

Stars are very unforgiving – mount instability, tracking errors and poor optics can change them from ideal point sources into fuzzy or elongated blobs in an instant. Fortunately, there are several ways to put them right again.

One of the simplest methods works well for slightly elongated stars. Duplicate your base star image and set the blend mode of the upper layer to darken. Nudging the upper layer in the direction of any star elongation will clip off any extensions. This technique is prone to introducing noise, however.

A more sophisticated method involves using the freeware IRIS program, available at www.astrosurf.com/build/us/iris/iris.htm. IRIS is powerful, but also quite technical. It does have tutorials though, and one of these – www.astrosurf.com/build/iris/tutorial12/doc30_us.htm – describes how to apply a Richardson-Lucy deconvolution to a square image with a black background to pull back some quite badly misshapen stars, making it useful for correcting errors caused by wind or tracking issues.

First draw a rectangle around an unsaturated star image – that's one that isn't pure white – then type 'RL 15 0' in IRIS's command window and press enter. This applies the Richardson-Lucy deconvolution to the image 15 times. Other values can be used too, and here experimentation can reveal what's best for your image. Finally, typing 'Gauss2 .7' and hitting enter will help reduce noise.

Fuzzy stars can be addressed using Photoshop or GIMP. Duplicate the base image and apply a high-pass filter to the upper layer (in Photoshop: Filter > Other > High pass) so that the stars appear sharp in a neutral grey background. Set the high-pass layer's blend mode to overlay to reduce star fuzz.

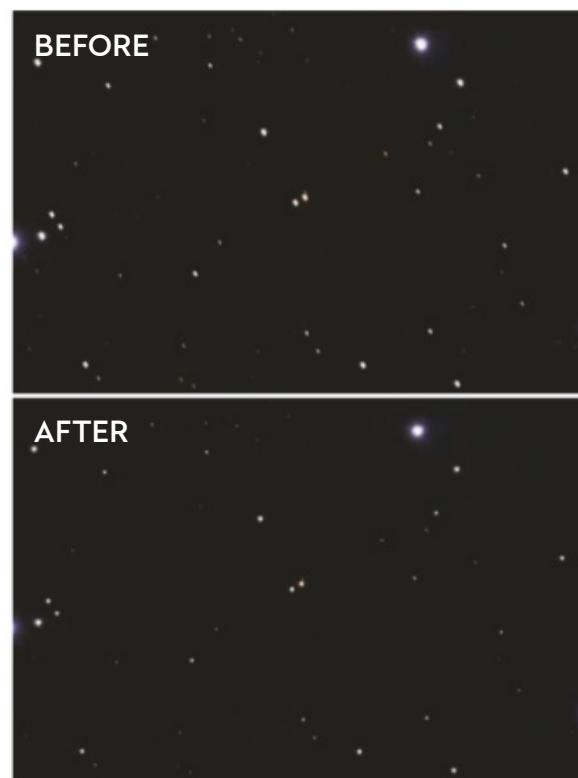
The final technique is to soften the edges of overly large circular stars. Load the image in Photoshop, then create a curves adjustment layer (Layer > New adjustment layer > Curves). Remove the layer mask that appears as a default by right-clicking on it and selecting Delete Layer Mask.

Select the image and use the magic wand tool (set to non-contiguous,

with a tolerance of 60) to select the brighter stars. Feather the selection by four pixels, then select the curves adjustment layer and add the selection as a layer mask (Layer > Add layer mask > Hide selection).

This adjustment layer now controls the parts of the image that are not stars. Click on the image to bring back the

selection (Select > Load selection), then invert it (Select > Inverse). Create a new curves adjustment layer and name it 'Stars' – the selection will automatically be brought in as a layer mask. Changing this adjustment curve will affect the appearance of the stars: bending it downwards will make them appear smaller and sharper.



▲ Top: a small tracking error has created elongated stars in this shot of the Pleiades
Above: fix by nudging a copied image with its blend mode set to darken in Photoshop



▲ Top: tracking errors have elongated the stars in this shot of the Lagoon Nebula
Above: applying a Richardson-Lucy deconvolution in IRIS gives a better image



▲ Top: the stars in this image of part of Orion's Sword are slightly fuzzy
Above: sharper stars are visible after applying a high pass filter



▲ Top: part of the Coathanger Cluster (Collinder 399) with slightly fuzzy stars
Above: editing the stars with a curves adjustment layer makes them sharper

ENHANCING STAR COLOUR

How to rescue overexposed stars and restore their true colours

Look carefully at a photograph of a bright star and it'll probably look pure white. This is because during a long exposure the star becomes washed out. The only way to avoid this is to reduce your exposure times to levels that are way too short. Doing so may allow you to capture the full glory of the star's true colour, but the rest of the image will be dark and uninspiring.

Fortunately, even when stars are overexposed, a trace of their colour remains at the very edge of their shape. Following the steps below, you'll be able to restore some of the natural vibrancy of the night sky. You'll give the stars back their original hue and create a more natural-looking end result.



▲ The stars of M35 are muted in the original, but regain their vibrancy after processing

STEP BY STEP: The process of enhancing star colour



1 Find the colour

Load your image and examine the stars closely. Notice the ring of coloured pixels around the bright core of the star. This is the colour we're going to reintroduce.



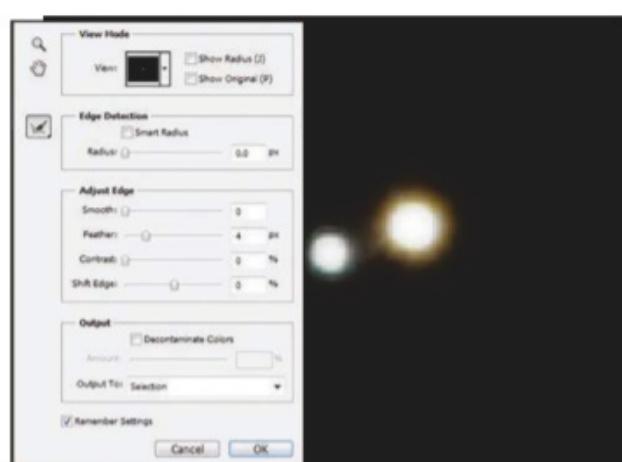
2 Select the star

Select the magic wand tool (set at non-contiguous, tolerance 60) and click on a star core. If non-star pixels are selected, deselect them.



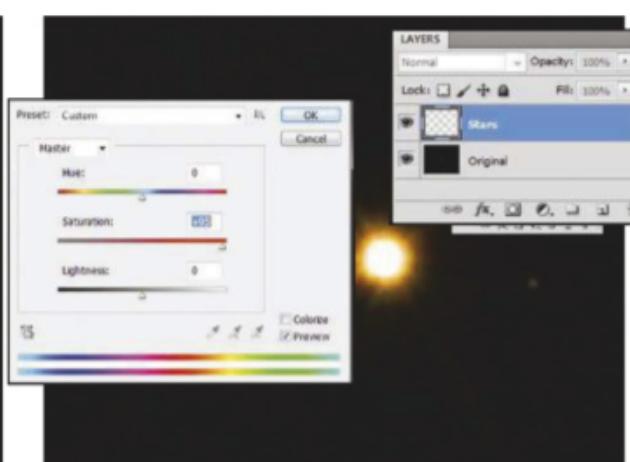
3 Expand selection

Expand the selection by a few pixels until it just encompasses the entire star. Examine the selection closely since the coloured ring needs to be covered too.



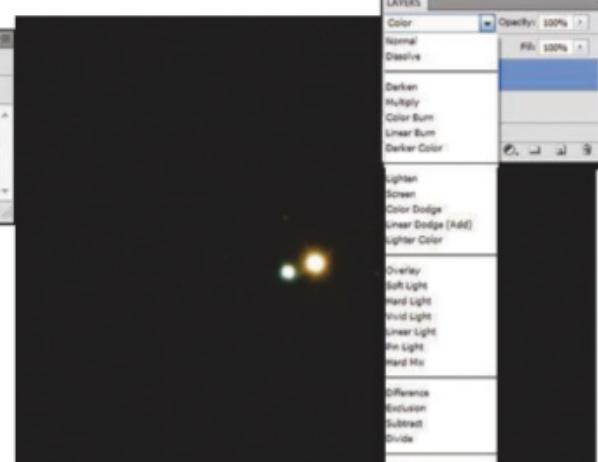
4 Feather and copy

Feather the edge of the selected areas by a couple of pixels to soften them. Copy the stars and paste them into the image as a new upper layer.



5 Saturate and blur

Ensure the star layer is active and set its saturation to 95. Apply a Gaussian blur of around one pixel. Try different values to see what works best.



6 Blend

Set the blend mode for the upper, now coloured, star layer to colour. Adjust the transparency of this layer as you see fit. Flatten the image and save as a new file.

NARROWBAND IMAGING

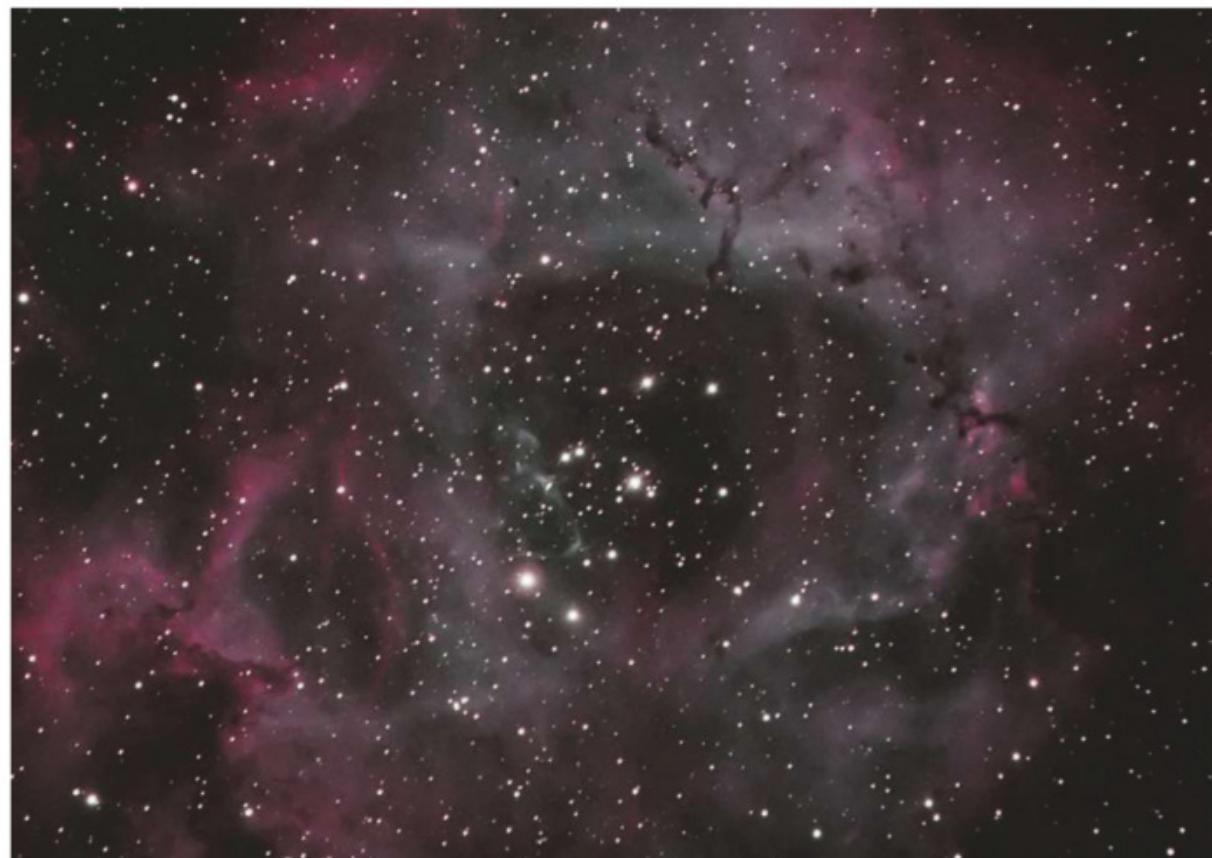
The RGB alternative that paints the Universe in a new light

Narrowband imaging is a popular way to take dramatic images of deep-sky objects, both for scientific and practical reasons. When imaging with a narrowband filter, only a certain range of wavelengths is passed through to the camera's image sensor. This range defines the filter's passband, which for deep-sky narrowband filters is typically between 10nm and 100nm.

Narrowband filters are set so that their passband's central wavelength is the same as a strong emission line from an element, such as hydrogen-alpha (H_a). The filter is then named after this emission line. Consequently, the filters pick out the light emitted by specific atoms in an object. They also prevent interference from other sources of light, so long as those sources don't emit in the wavelength range that the filter lets through. This means that narrowband filters can help you to overcome certain types of light pollution.

Shots taken with certain narrowband filters can be used to build pseudo-colour images of deep-sky objects: you use the narrowband images as you would the R, G and B components to build a full-colour RGB image. There are various ways to do this and some produce results that are more realistic than others.

ALL PICTURES: PETE LAWRENCE



▲ Narrowband filters can help you to capture stunning sights in spite of light pollution

Replacing RGB shots with images taken through sulphur II (SII), H_a and oxygen III (OIII) filters creates a wavelength-ordered result. Ideally, you should stretch all the channels so that their histograms have a similar tonal range first.

For a synthetic RGB colour result, a mix of 33 per cent SII and H_a for red, OIII for green and 33 per cent H_a and OIII for blue

gives an image close to what you would expect from traditional RGB filters. There's also bi-colour narrowband imaging, which uses just two filters to create the final colour image, saving time and cutting down on filter cost. As many objects don't emit much blue light, a combination of H_a for red, and OIII for green and blue is one way to do this.

FILTER TYPES

An at-a-glance guide to narrowband filters



Hydrogen-alpha

H_a (656.28nm) filters pick out ionised hydrogen in nebulae and galaxies. Various bandwidths are available: wider ones can be used with DSLRs, narrower ones with mono CCDs.



Sulphur II

SII (671.6nm and 673.1nm) filters let through a double emission line of sulphur commonly seen in nebulae. These filters are normally only used with astronomical CCDs and modified DSLRs.



Oxygen III

OIII (495.9nm and 500.9nm) filters pass the double line of oxygen, useful when imaging planetary nebulae and supernova remnants. These filters work well with DSLRs and astronomical CCDs.



Hydrogen-beta

H_b (486.1nm) filters let through blue light and are good for some objects, including the Horsehead Nebula (above). These filters work with DSLRs and astronomical CCDs.

COMET PROCESSING

Combine a stacked comet image with a star field

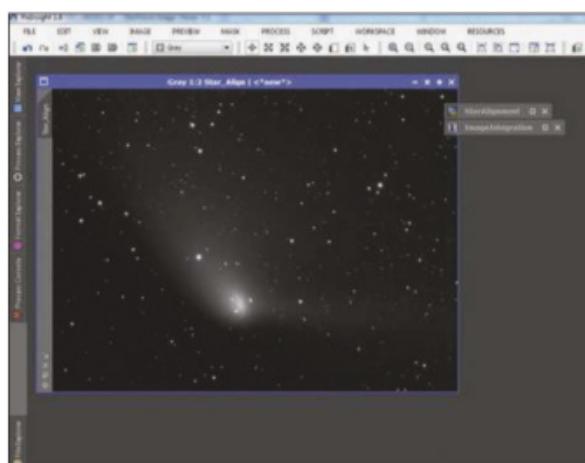


PixInsight is a purpose-built image processing application designed specifically for astrophotography. It's a commercial program with a modest learning curve but, once mastered, it can give you powerful and detailed control over your image processing workflow.

In the example below, we show how to combine Solar System with deep sky photography by processing a set of comet images with PixInsight. The aim is to combine a stacked image of the moving comet with a stacked image of the background star field while keeping both elements sharp.

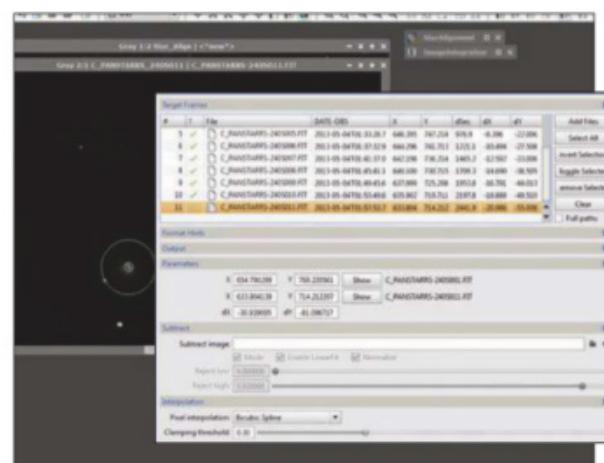
The example assumes you've taken a set of images of a comet. These should be calibrated using PixInsight's ImageCalibration routine in preparation for registration and stacking.

STEP BY STEP: Use PixInsight to calibrate and blend



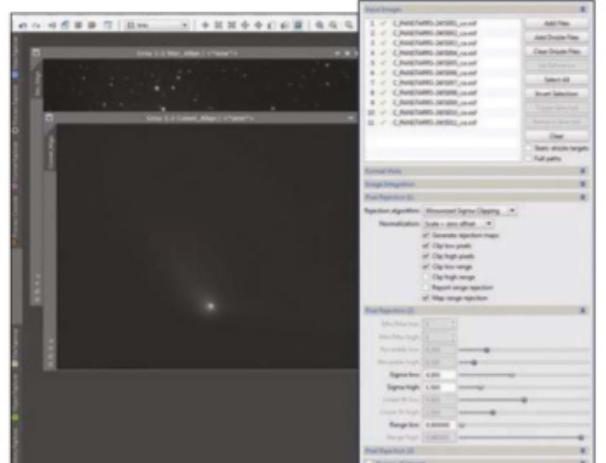
1 Align the stars

Use the StarAlignment tool to produce a set of star-registered images. The ImageIntegration tool can then be used to combine these to produce a sharp star-aligned image with a blurred comet.



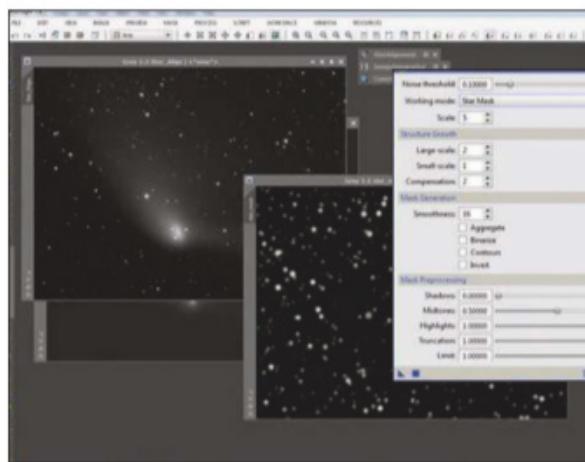
2 Identify the comet

Open CometAlignment and add the calibrated images. Double-click on the first image. Click on the centre of the comet's head. Close the image and repeat for the last image in the list.



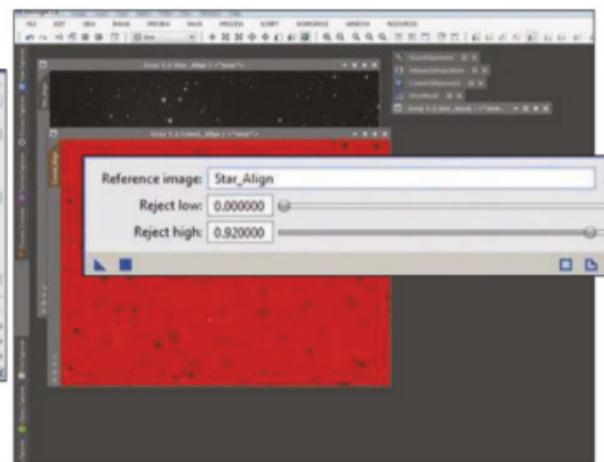
3 Align the comet

Select your output folder and global apply. Clear the ImageIntegration list then add new results. Set a value of 1.5 for Pixel Rejection (2), Sigma High. Global apply to produce a comet-aligned image.



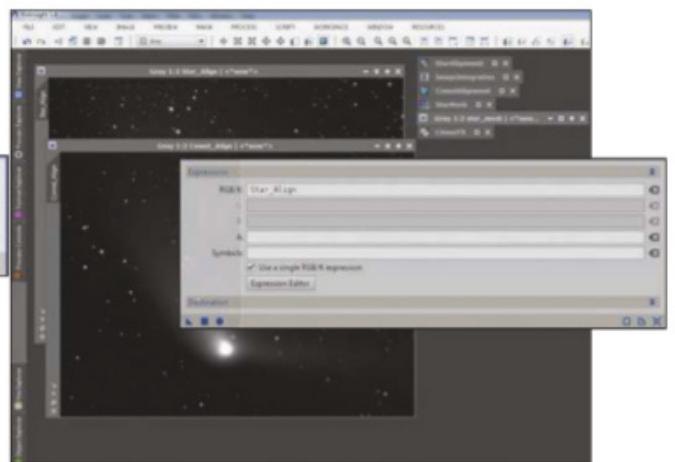
4 Create a mask

Open the StarMask tool and apply to the star-aligned image to generate a mask. A Histogram Transformation can be applied to the mask. Adjust the mid-point slider to re-introduce fainter stars.



5 Clone and fit

Clone out the comet head in the mask. Select LinearFit and apply it to the comet-aligned image to align histograms. Apply the mask to the comet-aligned image.



6 Combine and save

Open PixelMaths, click Expression Editor > Images and select the star-aligned image. Click OK. Apply PixelMaths to the comet-aligned image and remove the mask. Finally, save the finished image.

BBC

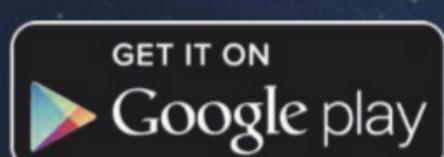
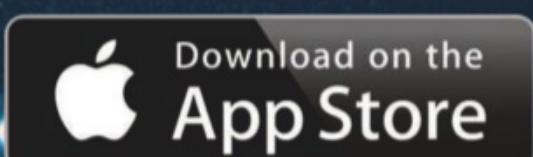
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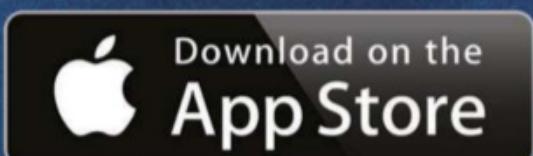


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WHAT TO DO NEXT

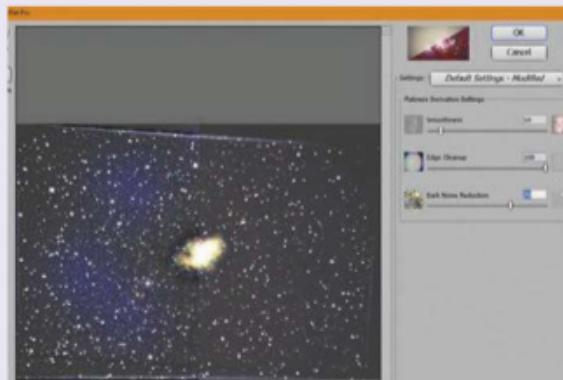
We've come to the end of our special edition, but your astrophotography journey is only just beginning. We've given you a thorough grounding in how to take great astronomical images, from simple starry scenes to close ups of the planets of our Solar System and beyond, but – as with

anything else – practice and experience count for a lot too. And, of course, there are many more wonderful night-sky targets worthy of your attention than we could cover in these pages.

So where do you go from here? There is no single right answer. Some astrophotographers specialise in

imaging particular objects – galaxies, for example. Some never use a telescope, relying solely on a DSLR and tripod for wide-angle nightscapes. Some only make timelapses. It really is up to you, but below you'll find some parting advice to help you discover where astrophotography can take you.

PRACTISE YOUR PROCESSING



Despite its formidable reputation, image processing has the potential to give you an equal if not greater thrill than that of getting the initial capture – especially once you start to see details emerge from what may be rather flat original images. Of course, this thrill can easily overtake you: knowing where to stop is as important as knowing where to start.

PLAN AHEAD

No astronomical target is visible in the night sky all the time – and even when it is, it may not be well placed for photography. So it's worth planning your imaging in advance. There are various planetarium programs that can help you, including the freeware Stellarium and Cartes du Ciel. Planning also extends to your setup: make sure your telescope is collimated and has cooled beforehand. Sadly, no amount of preparation can account for the weather!

CHALLENGE YOURSELF

We've shown you the techniques and how to apply them to a few targets – now it's up to you to test them out on the other denizens of the night sky. If you're beguiled by the Moon, explore it as the terminator moves and throws new features into relief; if you're enchanted by the planets, try for Venus's crescent; if you've seen enough of NGC 7000, try for another nebula, such as famous M42 in Orion.



SEND US YOUR IMAGES

We love seeing your images and all the detail you manage to tease out of the night sky. We even print a selection of them in our Astrophotography Gallery, which appears in every issue of *BBC Sky at Night Magazine*. If you capture a photo you're particularly proud of, send it in – you may even win the monthly prize! Email your pics to contactus@skyatnightmagazine.com. And don't forget, to enter your photo for the annual Insight Investment Astronomy Photographer of the Year competition – keep an eye on www.rmg.co.uk/astrophoto for details.

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